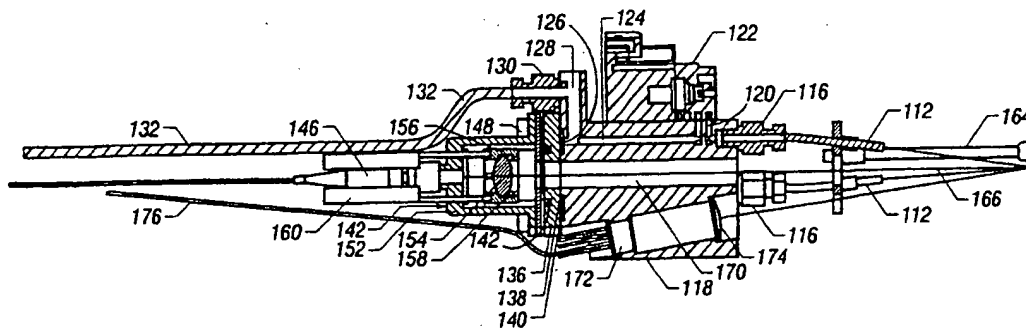# PCT

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(71) Applicant (for all designated States except US): THERMO-LASE CORPORATION [US/US]; 10455 Pacific Center Court, San Diego, CA 92121-4339 (US).

(72) Inventors; and
(75) Inventors/Applicants (for US only): TANKOVICH, Nikolai Inanovich [RU/US]; 9361 Stargaze Avenue, San Diego, CA 92127 (US). KOLINKO, Vladimair Grigorievich [RU/US]; 12682 Torrey Bluff Drive, #227, San Diego, CA 92130 (US). FINE, David [US/US]; 109 Lexington Road, Lincoln, MA 01773 (US). MILNER, Thomas [US/US]; Austin, TX (US). FRAIM, Freeman [US/US]; 9 Plymouth Road, Lexington, MA 02173 (US). DIBELLA, Francis [US/US]; 1 Haslett Street, Roslindale, MA 02131 (US). LEFEBVRE, Michael, Joseph [US/US]; 12795 Via Teceto, San Diego, CA 92130 (US).

(74) Agent: WAINER, Jonathan, J.; Fish & Richardson P.C., 225 Franklin Street, Boston, MA 02110-2804 (US).

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(54) Title: SKIN COOLING APPARATUS AND METHOD FOR LASER ASSISTED SKIN TREATMENTS

(57) Abstract

A cooling method and apparatus for use in combination with a laser for long-term hair removal and skin peeling. The cooling may be used with such hair-removal or skin peeling, with or without a contaminant that absorbs laser energy. Either concurrently or approximately concurrently with the illumination, the skin surface is cooled so that skin tissue is maintained at temperatures below that which could cause tissue damage. Preferably, the cooling is applied as cryogenic blasts of a cooling medium, e.g. a refrigerant, nitrogen, or cooled air, and may be performed in a cyclical fashion with heating form laser illumination. Optionally, the cooling method and apparatus may be used with an impingement technique and associated device for breaking up the formation of fluid vapor layer immediately above the skin surface for better control of the cooling process.

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SKIN COOLING APPARATUS AND METHOD
FOR LASER ASSISTED SKIN TREATMENTS

This invention relates to devices and methods
5   for skin cooling during laser-based skin treatment,
including hair-removal and skin peeling.

Background of the Invention

Three techniques for laser-based hair removal are
described in the following United States patents:
10   Weissman et. al., Method for Laser Depletion Device and
Method, Patent No. 4,388,924; Sutton, Depletion Device
and Method, Patent No. 4,617,926; and Mayer, Depilation
by Means of Laser Energy, Patent No. 3,538,919. All of
these devices and methods are for the removal of hairs
15   one hair at a time with a narrowly focused laser beam.
Therefore, they are relatively inefficient and time
consuming. U.S. Patent No. 5,059,192 to Zaias, issued
October 22, 1991, discloses a process for using a laser
beam at a wavelength that is matched to the melanin found
20   at the base of the hair follicle and papilla. An
improved laser-based hair removal process is disclosed by
Tankovich in U.S. Patents 5,425,728, and 5,226,907 that
includes a contaminant in combination with a laser.

Removal of a few surface layer's of a person's
25   skin will generally result in younger looking skin.
Recent attempts to remove the skin with a laser have
resulted in blistering.   U.S. Patent 5,423,803 to
Tankovich et al. discloses a process for removal of
superficial epidermal skin cells in the human skin
30   without blistering by using a contaminant with laser for
relatively gentle skin peeling.

Other types of thermally mediated skin procedures
involve the use of a laser. For example, laser treatment
of selected hypervascular cutaneous malformations such as
35   port wine stain birthmarks, hemangiomas, and

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telangiectasias. These procedures, and also laser hair
removal, require photocoagulation of targeted subsurface
blood vessels, or damage to hair follicles, while
protecting the overlying epidermis from thermal injury.
5 Laser skin peeling, too, can produce thermal effects in
the skin and unwanted damage to skin is possible.
Cooling may be desirable or even necessary if the
temperature of the skin approaches unsafe levels to
protect superficial skin structures from undesired
10 thermal injury.

Any of the laser-based skin treatments discussed
above, as well as others not discussed would be enhanced
by the additional of cooling to prevent damage to non-
targeted biological tissue. Accordingly a cooling
15 method and apparatus for use in laser-based skin
treatment, which may include hair removal and skin
peeling is needed.

It is known to use a low-boiling point refrigerant
liquid to cool the skin. However, there is a danger of
20 damaging the skin with this type of coolant. Prior
attempts to address the safety issue have typically
involved a cyclic method that starts by applying some
cooling medium to the epidermis, then applying a pulse of
laser light that penetrates the epidermis and heats the
25 dermis, and then cooling the epidermis layer again in
attempts to regulate heat transfer and protect the
epidermis. A typical first cooling step may cool the
epidermis from 36 C to 5 C, and then subsequent cooling
attempts apply enough cooling medium to keep the
30 epidermis in this temperature range. with this method it
is difficult to heat the target tissue sufficiently to
achieve the type of thermal damage desired.

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Summary of the Invention

In order to redress the problems discussed above, and those which will become apparent upon reading the description below, the present invention provides a
5   cooling method and apparatus for use in combination with laser-assisted skin treatment, including but not limited to long-term hair removal and skin peeling.

In one optional embodiment of the invention, heating-cooling sequences are used to eliminate or
10   minimize any pain or damage to skin tissue other than tissue adjacent to the hair ducts. Generally in a preferred method heating is followed by cooling and then each is cyclically applied.

Cooling may also be provided in a predetermined
15   timed sequence, such as continuously and possibly concurrent with illumination.

Generally the apparatus of this invention may provide cooling for laser-based skin treatment by application of a cooling medium, such as a cold air
20   blast, or a cryogen-spray. The apparatus of this invention may include a handpiece that provides both optical and cooling capability. In one embodiment of this invention, the combination is used with a dry air circulation system that helps prevent undesirable effects
25   from moisture from air freezing on the skin surface caused by a cryogen-based cooling spray.

In another aspect of the invention, a uniform temperature profile may be maintained in a three-dimensional tissue volume by arrangement of cooling
30   nozzles to achieve control of sub-epidermal depth, and by maintaining control over a two-dimensional skin surface depth.

In still another aspect of this invention, a cryogen storage vessel included with the cooling
35   apparatus is provided with a secondary pressure control

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mechanism for further assistance with achieving a uniform temperature profile over a targeted volume of biological tissue.

Another use of this invention is in combination
5 with an Er:glass laser system for the nonablative laser treatment of facial rhytides. The laser operates at a wavelength of 1.54 μm and is preferably delivered to the skin using a fiberoptic handpiece. At this wavelength, the primary tissue chromophore for absorbing the laser
10 energy is water, which has an absorption coefficient of approximately 10 cm^{-1}. The laser delivers a sequence of pulses of light at less than 10 msec duration, and at a 50 Hz repetition frequency and pulse radiant exposures up to 40 J/cm^2.

15   Preferably, a cryogenic spray cooling device is used to cool the epidermis prior to, and immediately following, laser heating in some aspects of the invention. Such a device uses a multiple nozzle architecture to deliver coolant to the skin surface. The
20 nozzles may be temporally fired in a series of rapid pulses with an appropriate duty cycle which allows the user to tailor a specific temperature depth profile while maintaining an acceptable surface temperature.

Precise timing of the laser heating and cooling
25 pulses may be controlled by computer, and other variables such a fluid flow volume and rate may also be so controlled.

Brief Description of the Drawing

The invention will best be understood with
30 reference to the detailed description below and the drawing figures briefly described below, and in which similar or identical reference numerals describe the same or similar elements:

Fig. 1 is a drawing of a section of human skin
35 showing a growing hair;

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Figs. 2A, B, C and D show a cross section of skin and 3 hairs during 4 stages of a process of one embodiment of the present invention;

Figs. 3A and 3B. shows qualitatively the paths of
5 the photons of a laser pulse showing absorption in a carbon-oil suspension;

Fig. 4 A through C shows an experiment with turkey skin, egg white, a partially contaminated hair and a laser beam to demonstrate some of the elements of the
10 present invention;

Figs. 5A and 5B show another experimental set up to demonstrate elements of the present invention;

Fig. 6 illustrates a preferred embodiment providing a photon pathway through hair ducts to the
15 papilla region;

Fig. 7 is a graph showing a preferred illumination-cooling sequence;

Fig. 8 is a simplified-schematic illustration of a cooling system useful for achieving the desired thermal
20 effects of this invention;

Fig. 9 is a simplified-schematic illustration of a handpiece providing optical and cooling functions for use with the cooling system of Fig. 8;

Fig. 10 is a simplifed-schematic illustration of
25 another embodiment of a cooling system useful for achieving the desired thermal effects of this invention with a cryogenic-based evaporative cooling system, and including an alternative hand-held applicator useful for providing cooling and optical functions;

30   Fig. 11 is a plan (bottom) view of an optical portion of the handpiece of Fig. 10 showing a preferred arrangement of respective nozzles for discharging cooling and dry air spray;

Fig. 12 is another plan (bottom) view of an
35 alternative optical portion for the handpiece of Fig. 10

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showing another preferred arrangement of respective
nozzles for discharging cooling and dry air spray;

Fig. 13 shows a secondary pressure vessel for
adjusting pressure of a cryogen-refrigerant before
5 delivery to the nozzle of the cooling system shown in
Fig. 10;

Fig. 14 shows an arrangement of cryogen-spray
nozzles for achieving a desired temperature profile
including a uniform temperature distribution in a volume
10 of biological tissue;

Figs. 15-20 are views of a multiple nozzle
handpiece, in which FIG. 15 is a perspective view, FIG.
16 is a side elevation view of the handpiece without the
housing, FIG. 17 is rear end view of the handpiece
15 without the housing, FIG 18 is a section view through
line 18-18 of FIG. 17, FIG. 19 is tow plan view of the
handpiece without the housing, and FIG. 20 is a front end
view of the handpiece without the housing;

Fig. 21 is a schematic of the cryogenic system for
20 use with the handpiece illustrated in Figs. 15-20; and

Fig. 22 is a schematic illustration of a coolant
jet directed to a skin surface.

Detailed Description of the Invention

The invention described below includes a cooling
25 apparatus and method useful for any laser-assisted skin
treatments, including but not limited to laser-assisted
hair removal or skin peeling, and also including other
sub-dermal dermatological applications. Although hair-
removal is described in detail below as one example of
30 the usefulness of the cooling apparatus and method, one
skilled in the art will recognize, in view of the
teachings below, that the cooling invention is generally
useful for laser-assisted skin treatment, including
laser-based skin peeling, as disclosed in the

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incorporated U.S. Patent 5,423,803. For purposes of
illustrating the cooling invention's applicability to
hair-removal, a detailed description of laser hair
removal processes is included now.

5 **Human Skin and Hair**

       A section of human skin showing a cross section of
one hair is shown in FIG. 1. The FIG. 1 drawing shows a
hair shaft 33, a hair duct 31, a nerve ending 34, a sweat
gland 35, a sebaceous gland 38 and arteries 36, veins 37,
10 and papilla 32.

Graphite

       In the graphite form of elementary carbon, each
carbon atom has three near neighbors and a fourth
neighbor at a considerably greater distance away, the two
15 lengths being 1.42 Å and 3.42 Å, respectively. (10,000
Angstroms equal 1 micron.) The network of the three
nearest neighbors is planar and extends in the two
directions of the plane to the boundaries of the solid.
The binding forces between the planes are weak and the
20 planes can slip past each other very readily. For this
reason, graphite can be used as a lubricating material.
Thin layers of graphite can be removed by abrasion and
this property is exploited in the ordinary lead pencil in
which motion of the graphite rod over paper causes thin
25 layers of the solid to be rubbed off and spread on the
paper. For many years laser workers have used paper
thinly coated with small particles of graphite to examine
the cross section power of certain laser beams. The
energy of many laser beams is readily absorbed by the
30 carbon particles and many of the particles react
violently, exploding off the paper and leaving
"footprints" on the paper representative of the cross
sectional power distribution of the laser beam.

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Contaminant

A laser beam absorbing carbon suspension consists
of graphite powder in mineral oil. The particle size of
the powder is preferably about 1 micron and its
5 concentration preferably is about 20 percent by mass.
This suspension is used to contaminate the hair ducts, so
we sometimes refer to the suspension as the
"contaminant." The expression "contaminant" is also used
to refer to the particles of the suspension, as is
10 apparent from the context.

Cleaning

A section of skin with growing hairs is depicted
in FIG. 2A. The skin is preferably washed with soap and
water then rinsed with water and dried with a cloth
15 towel. The skin section is then cleaned with methyl
alcohol and allowed to dry.

Waxing

A next step in this embodiment is to physically
remove the hair shafts from the hair ducts in the skin
20 section to be treated. This may be accomplished using a
well-known temporary hair removal procedure known as
waxing. We prefer using a commercially available wax
marketed by Select Spa Source of Sausilito, California
under the trade name Nature's Own Pine Wax although a
25 wide variety of such waxes are available and would be
satisfactory. We follow the waxing procedure furnished
with the wax.

It is believed that removal of the hair from the
hair ducts greatly increases the space available in the
30 hair duct for the graphite based contaminant permitting a
much greater quantity of the contaminant to be
infiltrated into the hair duct. FIG. 2B shows the same
three hair ducts as FIG. 2A with the hair shafts removed.
Nevertheless, one skilled in the art will recognize that
35 waxing is only an optional step.

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Topical Application of Contaminant

The next step is to apply the described
graphite-oil contaminant to the section of skin to be
treated. The contaminant is applied to the skin in
5   quantities of about one gram per 10 square centimeters,
although the exact amount is not critical. The
contaminant is massaged thoroughly on the skin surface
for a period of about 1-minute for each 10 square
centimeters of skin surface. Our principal objective in
10 this step is to cause as much of the graphite particles
as feasible to infiltrate into the hair ducts in the skin
section. Our tests indicate that our graphite oil
contaminant can be infiltrated with this massage
technique into the hair duct to a depth of about 0.5 mm.
15 For a 100-micron diameter hair duct, this would
correspond to about 700,000 carbon particles in the duct.
There is great variation in the amount of graphite
infiltrated but we can assume for illustration purposes
an infiltration of 700,000 one-micron particles (about
20 1.4×10^{-6} grams of carbon particles.) At the conclusion
of the massaging step, the contaminant is present in the
upper part of the hair duct and the skin surface is
substantially covered with graphite-oil contaminant as
shown in FIG. 2C.

25 **Phases of Illumination**

As indicated above the present invention provides
a process with at least two distinct phases of
illumination with the objective of achieving maximum hair
destruction with otherwise minimal damage to skin tissue.
30 In a preferred process the illumination is provided by a
Nd:YAG pulse laser operating at a wavelength of 1.06
microns with a beam cross sectional area of about 0.5 cm².
Controls on the laser permit selection of short pulses of
10 ns duration using a Q switch and a long pulse duration
35 of about 100 microseconds (100,000 ns), with the Q switch

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disconnected. (The pulse duration is approximately the interval of time over which the pulses are at least one half maximum power.) Pulse energy can be adjusted to between about 0.1 J and 1.25 J, corresponding to 0.2 J/cm^2

5 and 2.5 J/cm^2 for the 0.5 cm^2 beam.

Explosion Phase

We refer to the first phase of our illumination process as the "explosion phase" in which particles are exploded. The laser is adjusted to produce about 1 Joule

10 per pulse, which is equivalent to about 2 J/cm^2 since the beam cross section is about 0.5 cm^2. The pulse duration is about 10 ns and the repetition rate is about 10 Hz. Each portion of the skin section to be treated is illuminated with about two to three pulses. This is done by scanning

15 the 0.5 cm^2 10 Hz beam over the skin surface at the rate of about 2 cm/s.

Each pulse contains about 1 x 10^{19} photons. The 1-micron graphite particles are very highly absorptive of the 1.06-micron laser photons. We estimate the absorption

20 coefficient of graphite to be between several thousand to about 100 thousand times greater than the absorption coefficient for typical skin tissue. The penetration depth for 1.06 micron photons in graphite is substantially less than 1 micron so substantially all

25 photons encountering a particle are absorbed by it. The 1.06-micron photons are well scattered by skin tissue. The scatter coefficient for dermal tissue is estimated to be about 100 cm^{-1} whereas the absorption coefficient is estimated to be about 0.33 cm^{-1}. Therefore, the length of

30 the path traveled by photons between scatters is estimated to be about 100 microns and the path traveled in the dermis before absorption in the dermal tissue is estimated to be 3 cm. The result of the large scattering is that the 1.06-micron photon flux builds up and is

35 actually greater (by a factor of about 5) just below the

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surface of the skin than the incident flux on the surface
of the skin. At two to three mm below the surface (about
the depth of most hair roots) the flux has decreased but
is still about equal to or maybe a little less than the
5   incident flux. Almost all of the photons entering the
skin surface are ultimately absorbed in the carbon or
absorbed in the skin tissue.

        The cross sectional area of a 1 micron particle is
roughly 1×10^{-8} cm^2 so the energy absorbed by a typical
10 particle out of a 2 J/cm^2 flux is in the range of about 2
$\times 10^{-8}$ J. This is a very small amount of energy but the
particle is also very small (with a volume of about 1 x
10^{-12} cm^3). Its density is about 2 gm/cm^3 and its average
specific heat is about 2 J/gmC over the temperature range
15 from ambient up to its vaporization temperature.
Therefore, each pulse pumps enough energy into the
graphite particle to substantially raise its temperature.
Graphite vaporizes at about 3,600°C.   It is believed
that only a portion of the energy absorbed by the
20 particle is used to heat it from 27°C (normal skin
temperature) to its vaporization temperature. The
remainder of the absorbed energy is released in a
miniature explosion of the particle in which a portion of
the particle is vaporized and the particle is broken into
25 smaller particles, which recoil away from the explosion
site. The explosion also creates a shock or pressure
wave, which pushes other particles away from the
explosion site. The heat capacity of carbon average about
2 J/gm°C over the range 0 to 3,600°C. The heat content to
30 raise the temperature of graphite to the vaporization
point is then about 7,200 J/gm. Thus, in our example
(7,200 J/gm) x (2 $\times 10^{-12}$ gm) = 1.4×10^{-8} J of the
absorbed laser energy is used to raise the temperature to
the vaporization level. The remaining 0.6×10^{-8} J
35 absorbed causes the vaporization of a portion of the

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graphite particles. The heat of vaporization of carbon is
about 6×10^4 J/gm; therefore, the energy needed to
vaporize all of the 1 micron (2×10^{-12} gm) particle is
about 12×10^{-8} J. Hence, in this illustration only about

5   5 percent of the particle is vaporized with each pulse.
        One effect of the miniature explosions is to blow
essentially all of the particles off the surface of the
skin. Some of the particles and portions of particles in
the upper parts of the hair ducts are blown out of the

10   hair ducts. Most of the particles in the upper portion of
the hair ducts, however, are shielded to some extent by
particles surrounding them and are forced further down
the ducts by the explosion of particles near the top of
the ducts. FIG. 2D shows some typical distribution of

15   graphite particles in the ducts after the conclusion of
the explosion. If we assume that the quantity of graphite
in the typical duct is roughly 1.4×10^{-6} gm (700,000
particles) we can estimate the total energy absorbed in
each hair duct. For illustration, if we have 700,000

20   particles in the duct and assume an average of 2×10^{-8} J
absorbed per particle per pulse, we would estimate an
absorbed energy of about 14×10^{-3} J/pulse. This is
equivalent to the amount of energy needed to increase the
temperature of a cylinder of water 3 mm long and about 67

25   microns in diameter by 80 degrees C. The estimate could
be much higher if we assume greater quantities of
particles and if we take into account flux buildup near
the skin surface. Skin tissue has a specific heat which
is about the same as water. From this illustration we

30   expect that we achieve some damage to skin tissues within
a few microns of the upper part of the hair duct during
the explosion phase but probably not enough to devitalize
the hair. Also, some damage may result from the
shockwaves or pressure waves. However, the main advantage

35   of the explosion phase is that particles are forced down

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the duct to the region of the duct near the papilla
through which growing hair receives its nourishment. The
explosion phase also clears substantially all particles
off the surface of the skin.

5 **Cooking Phase**

<u>First Cooking Phase Embodiment</u>

The second phase of the illumination phase is
referred to as the "cooking" or "thermal phase" because
the objective of this phase is to heat the skin tissue
10 adjacent to the hair duct to a temperature high enough to
permanently devitalize (kill) it, so that the tissue
cannot support future hair regrowth. A first embodiment
of a cooking phase is described as follows. Prior to
starting this phase, graphite particles remaining on the
15 skin surface are cleaned off as completely feasible with
a cloth soaked in mineral oil. This also tends to fill in
void spaces in the hair duct (especially at the top of
the duct) with mineral oil. Mineral oil transmits 1.06
microns light very well. We target a volume within about
20 150 microns radius of the center of the hair duct. The
heating is accomplished primarily by applying heat from
laser illumination to the graphite particles, which are
now distributed deeply in the hair duct. Laser photon
absorbed in the graphite particles include photons
25 scattered into the hair duct from the surrounding skin
tissue and also photons transmitted down the hair duct
through mineral oil which now fills the upper part of the
duct. Heat is transferred by conduction from the graphite
to the surrounding tissue. During the "cooking phase" we
30 apply heat energy slowly enough so that we avoid
substantial vaporization or fracturing of the graphite.
By so doing we can apply heat to the tissue via the
graphite particles a very large number of times.

This first heating-cooling embodiment is described
35 in FIG. 7. Two 100-ms, 20J/cm2 Nd:YAG 1.06-micron pulses

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are spaced apart by 150 ms, followed after 50 ms by 40-ms
skin surface cooling pulse at 0 degrees C, followed after
10 ms by a third 100-ms, 20 J/cm2 Nd:YAG pulse which is
followed again after 50 ms by another 40-ms cooling
5 pulse, followed by a similar fourth laser pulse and
another cooling pulse and a final fifth laser pulse.
With this process about 100 Joules per square centimeter
is deposited into the skin without any significant pain
or over heating of the skin. However, the bulk of the
10 skin tissue about 2 to 3 mm below the skin surface near
the hair follicles is raised from the normal temperature
of about 36 degrees C to a temperatures a few degrees
below the skin temperature pain threshold and the
threshold for tissue damage. Skin tissue within a few
15 10s of microns of the graphite particles in the hair
ducts are being heated by relatively large quantities of
laser energy absorbed then conducted away by the graphite
particles and also directly by the laser pulses.
Therefore, this tissue is heated to a temperature
20 substantially in excess of the threshold for tissue
damage. Thus the tissue surrounding the follicle is
effectively devitalized without any significant damage to
skin tissue in general. Since the volume of high
temperature is very small and concentrated there is no
25 significant pain. The cooking phase may be repeated as
many times as desired because there is no diminution of
the quantity of graphite during this phase. We recommend
that the cooking phase be repeated at least 3 times, but
to be sure of a good result about 10 repetitions is
30 suggested.

Second Cooking Phase Embodiment

In a second cooking phase embodiment, we
disconnect the Q switch so that our laser produces pulses
of about 100 microseconds duration with a pulse energy at
35 2 J/cm^2 and the repetition rate at 10 Hz. In this

embodiment we cool the skin with 0 degree air
concurrently with the laser illumination.

The skin is scanned so that each portion of the
section of the skin being treated is illuminated for only
5   about 2.5 seconds (about 25 pulses) before moving to
another skin section. Each pulse in addition to heating
the graphite, applies heat generally to the skin tissue
and increases the temperature of the skin tissue about
0.5 to 1.5 degrees C, so more than 30 pulses could cause
10   the skin portion being illuminated to become very warm.
In our experiments burning pain is experienced after five
to seven seconds of 2 J/cm^2 10 Hz pulses (100 to 140
Joules/cm^2); therefore, we limit the number of laser
pulses periods to well below this threshold.
15   Each portion of the skin section being treated
receives about 20 scans for a total of about 500 pulses.
(This takes a total of about 50 seconds per portion.)
Each 1 micron particle absorbs very roughly about 2×10^{-8}
Joules per pulse or about 50×10^{-8} Joules per 2.5 second
20   scan. Heat diffuses out from the graphite particles to a
distance of about a few tens of microns during the first
few milliseconds after the start of a scan and diffuses a
few hundred microns in one second. If we assume the
equivalent of 500,000 one micron cubic particles per
25   duct, each duct would receive roughly about 0.25 Joule
per each 2.5 second scan. This 0.25 Joules would be
sufficient to increase the temperature of a volume of
water 3 mm long and 563 microns diameter by 80 degrees C.
The specific heat of skin tissue is about the same as
30   that of water. Skin tissue is devitalized (killed) if
kept at a temperature of 70 degrees C for about 1 second.
Skin tissue closest to the carbon particles will be
heated to temperatures much higher than 70°C. We estimate
that skin tissue within about 1 to 3 hair diameters of
35   the hair ducts is devitalized during this phase. Actual

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biopsy studies of both pig and human skin confirm these estimates.

Third Cooking Phase Embodiment

5   In another embodiment, the second phase illumination consists of about 2,000 pulses at 0.2 J/cm^2 with a pulse duration of 10 nanoseconds. This requires about 200 seconds per skin section but the cross section of our laser beam can be expanded by a factor of ten and the illumination scan time can be increased from about 3

10   seconds to about 12 seconds or longer without significant rich general skin burning. At 0.2 J/cm^2 the particles are heated to temperatures in the range of about 1,000 degrees C. Again, cooling is provided continuously and concurrent with the illumination.

15 **Clean-Up Phase**

During a third phase of the illumination process, which we call the "clean up phase", the skin section can be illuminated with about ten Nd:YAG laser pulses at 1.06 micron wavelength and 10 Hz, each pulse having an energy

20   density as in the first phase of about 2 Joules/cm^2 and a pulse width of about 10 nanoseconds. Again, the pulse duration is so quick that very little heat is conducted out of the particle during the pulse. As before, the power density of these pulses is about 200 Megawatts/cm^2,

25   enough to heat the particles to over 3,600 degrees C, cause explosions of the particles and vaporize with each pulse a portion (about 5 percent) of the particles. These explosions cause additional damage to the tissue surrounding the particles. Also, after about 10 to 30

30   pulses, the particles are mostly vaporized or broken into particles so small that they are invisible to the unaided eye. Any remaining particles small enough to be removed by the body's natural cleaning mechanisms.

EXPERIMENT WITH SMALL PARTICLES

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In order to confirm the above description of the
hair-removal process, we have conducted experiments in
which these small carbon particles were irradiated with
pulses of the type described above.

5 **Particles in a Bottle**

A small number (about 0.1 gm) of one micron size
graphite particles were placed in an enclosed glass vial
in an air atmosphere and irradiated with pulses as
described above under the "Explosion Phases" with no
10 scanning. The particles were continuously broken into
smaller and smaller particles and after about 10-15
pulses they vanished. We believe the very small particles
were oxidized to form CO or CO_2. When the same experiment
is conducted in an argon atmosphere the particles
15 continued to break into smaller and smaller parts until
they were nearly invisible to the unaided eye (i.e. about
0.1 micron to 0.05 micron).

Experiment with Fiber Optic Tube Simulating Hair Duct

We have also conducted laboratory experiments to
20 demonstrate the effectiveness of the explosion phase and
the cooking phase of the above-described embodiment. In
one experiment we infiltrated our carbon-oil contaminant
into the top of a 100 micron inside diameter, 5 mm long
fiber optic tube to a depth of about 1 mm. We then
25 blocked the bottom of the tube and irradiated the top of
the tube with one 10-ns pulse from our Nd:YAG laser at 2
J/cm^2. As a result of miniature particle explosions at the
top of the tube, graphite particles were distributed
throughout the tube with maximum concentration of
30 particles at the bottom of the tube. We then illuminated
the tube with 100 microsecond 2 J/cm^2 pulses for five
seconds. The heat absorbed by the carbon caused the inner
surface of the tube and tube's fiber clad to deform. A
tube without graphite was illuminated with 2 J/cm^2 for 25
35 seconds with no visible effect on the tube. In another

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test of a tube with graphite in it and illumination at 3
J/cm² for five seconds the tube melted.

Pig Experiment

     In other experiments we tested our preferred
5 process with pig skin in vitro. In one experiment to
examine the explosion phase of our preferred illumination
process, hairs in sections of the pig skin was removed
prior to the topical application of the contaminant and
in other skin sections the hair was not removed. After
10 the topical application of the contaminant, the skin
sections were illuminated with 1, 2, 5 and 10 pulses (all
at 10 ns duration) at power levels of 1 J/cm², 2 J/cm² and
3 J/cm². The skin was then biopsied to permit examination
of the follicles. The maximum and deepest contamination
15 was produced with 2 pulses at 2 J/cm². At 3 J/cm²
vaporization of the carbon became substantial. In those
sections where the hair was removed the graphite
particles completely filled the hair ducts with heavy
concentration at the bottom of the duct. In those
20 sections where the hair was not removed, the graphite
particles were distributed deeply into the duct, but
generally very few particles reached the bottom of the
ducts.

Hair in Egg White Experiments
25 **(1) Short-Pulse-High Power**

     FIGS. 4A, 4B and 4C are sketches illustrating an
experiment performed in order to demonstrate elements of
this hair removal process. Three layers of turkey
drumstick skin 10 were sandwiched between two glass
30 microscopic slides 8. The thickness of the 3 layers of
turkey skin was about 2 millimeters (approximate depth
below the skin surface of the bottom of human hairs). A
single human hair 16 about 10 cm long was coated over a 3
cm section with a mixture 18 of 1 micron particles of
35 carbon (graphite) and mineral oil (about equal mass). The

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hair was immersed in chicken egg white 14 contained in a
small (5 cm diameter) vial 12. The drawing is roughly to
scale except the diameter of the hair and the carbon-oil
contaminant is exaggerated.

5   The hair including the coated section was
illuminated with 100 pulses of laser radiation from a
Nd:YAG laser.

           The following is a description of the pulsed laser
beam:

10   Wavelength   1.06 micron
           Energy per pulse   1.5 Joules
           Beam area   1/2 cm²
           Energy density   3 J/cm²
           Frequency   10 pulses per second
15   Pulse duration   10 ns

Each pulse 20 passed through the slides and chicken skin
with no apparent effect on the checker skin. The beam
also passed through the wall of the vial and through the
egg white.

20   The beam was scanned over the hair so that each
portion of the hair received about 5 pulses. The beam had
no effect on the hair or the egg white except near the
section of the hair which was coated. In that section,
the carbon in the mixture absorbed sufficient energy from
25 the beam to cook the egg white immediately surrounding
the coated section of the hair. In this experiment we
could watch the cooking process because uncooked egg
white is transparent.

           FIG. 4B shows the result of the first 10 pulses of
30 beam 20 (about 3 pulses into the carbon) passing through
the elements of this experiment. The only discernible
effect of these pulses was an obvious heating and cooking
of the egg white immediately adjacent to the coated
section of the hair. Some fragments of carbon particles
35 were thrown off the hair but were trapped in the

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immediate surrounding egg white. These fragments were
further fragmented by subsequent pulses into very small
fragments or oxidized. FIG. 4C shows the results of 100
pulses. The egg white tissue in the immediate vicinity of
5 the coated section was cooked to a thickness of about 500
microns. There was no damage discernible in either the
turkey skin or anywhere else in the egg white or to the
hair itself other than the coated section. These
conclusions apparent to the unaided eye were checked and
10 confirmed under a microscope. Only a very few small
particles of carbon remained.

(2) **Long Pulse-High Energy**

FIG. 5A shows a drawing of another egg white
experiment conducted to test the cooking phase. Two
15 layers of chicken skin 50 were placed at the bottom of a
glass dish 52. Separate ends of a human hair 54 were
glued with "super glue" to paper clips 56 and the portion
of the hairs between the clips were coated with a
preferred graphite/oil contaminant 58 (about equal mass
20 of mineral oil and 1 micron graphite particles). The
hair-paper clip assembly was placed on the chicken skin
and the hair, paper clips and skin were covered with egg
white. The hair was then illuminated from below through
the chicken skin and the egg white with 100 microsecond
25 laser pulses 60 at 2 J/cm^2 at the rate of 10 Hz for about
2 to 3 seconds. This process was repeated several times
allowing for cooling between illuminations. With this
setup, the experimenter could watch the hot graphite cook
the adjacent egg white, and the hair, particles and egg
30 white can be viewed periodically with a microscope. Egg
white immediately surrounding the contaminant coated hair
was cooked with no damage to the skin or any egg white
not close to the contaminant. Also, after many repeat
illumination periods of about 2.5 seconds (during which
35 about 50 J/cm^2 was delivered), there was no detectable

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diminution of the carbon particles. Therefore, we
concluded that the "cooking" process (with in-between
cooling periods) could have continued indefinitely with
no apparent damage to the skin or egg white except the
5   egg white in the immediate vicinity of the contaminant.
(3) Short Pulse-Lower Energy
        The above experiment was also conducted as
described above but with pulses at 0.2 J/cm^2 with the Q
switch in place so that the pulse was 10 ns and 0.2 J/cm^2.
10 There was cooking of the egg white adjacent to the
graphite but no violent explosion or obvious
fragmentation of carbon particles. And at the conclusion
of a large number of pulses there was no substantial
diminution of the graphite particles. At 0.2 J/cm^2 about
15 250 pulses could be applied before general skin heating
would become a problem. With this approach we recommend
increasing the pulse frequency to 50 or 100 Hz.
Experimental Conclusion
        These experiments show that with 10-ns pulses and
20 2 J/cm^2 illumination carbon particles explode violently
(on a miniature scale) and are partially vaporized.
However increasing the pulse duration to 100 microseconds
(with pulse energy at 2 J/cm^2) or reducing the energy to
about 0.2 J/cm^2 (with a 10-ns pulse) permits delivery of
25 sufficient heat to the carbon to cook tissue with no
substantial vaporization or explosion of the carbon. This
permits the "cooking phase" to be continued indefinitely.
OTHER EMBODIMENTS FOR HAIR REMOVAL
Buckey Balls
30   Another potential method of increasing the
quantity of contaminant in the hair duct is to use very
small spherical particles. A carbon molecule meeting
these specifications has recently been produced and is
available commercially. These molecules are known as
35 Buckey balls or C_{60}. Buckey balls are carbon molecules,

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roughly spherical; each comprised of 60 atoms of carbon.
Buckey balls are commercially available, e.g., under the
name Buckminsterfullerene from Sigma Chemical Company
with offices in St. Louis, Missouri) at prices of about
5   $300 per gram. Our initial experiment with this form of
carbon contaminant indicates promising results. The
Buckey balls are very absorptive of Nd:YAG laser beams
and appear to infiltrate into hair ducts very readily.

Double Application of Contaminant

10   Another method of increasing the quantity of
contaminant in hair duct is to repeat the topical
application and explosion phase one or more times. Our
experiments indicated that the explosion phase opens the
ducts slightly wider providing more room for contaminant
15 on the second application. Increasing the quantity of
graphite in the duct increases the amount of heat we can
import to the duct during the cooking phase. Steps in one
variation of this method would include the following
steps:

20   1.   Waxing;
            2.   First topical application of contaminant;
            3.   First explosion phase;
            4.   First thermal phase with skin cooling;
            5.   Second topical application;
25   6.   Second explosion phase;
            7.   Second thermal phase with skin cooling; and
            8.   Clean up phase.

        For difficult hair removal cases steps 5, 6, and 7
could be repeated several times. On each repetition,
30 additional graphite accumulates in the hair duct,
permitting more and more heat to be imported during the
cooking phase. Another approach is the same steps as
listed above with the first cooking phase (step 4)
omitted. The cleanup phase removes substantially all

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graphite from the duct or fractures it into particles of
very small sizes.

Mineral Oil Path to the Papilla

        In another embodiment, our goal is to deposit
5   graphite particles as close to the papilla as possible
     and to fill the remainder of the hair duct with mineral
     oil. We then provide a cooking phase to provide maximum
     preferential heating of tissue in the papilla region of
     the hair duct. Steps in one variation of this method
10   would include the following:
             1.   Waxing;
             2.   Topical application of contaminant;
             3.   First explosion phase;
             4.   Clean skin surface with mineral oil;
15   5.   Apply mineral oil to skin surface and massage
                   into ducts;
             6.   Thermal phase with skin cooling; and
             7.   Clean up phase.
        We have demonstrated experimentally that mineral
20   oil (being transparent to the 1.06-micron light and
     having an index of refraction substantially greater than
     that for skin), will conduct light beams down the hair
     duct to the papilla area. Thus, absorbers in the papilla
     region receive illumination both from photons scattered
25   from the dermis and photons traveling through the mineral
     oil in the upper region of the hair duct. This effect is
     illustrated in FIG. 6. Note that we have shown the paths
     of five typical photons A, B, C, D and E. A and B are
     scattered many times in the dermis and are ultimately
30   absorbed in graphite particles in the bottom of the hair
     duct. Photon C travels down the hair duct through the
     mineral oil similar to photons in an optical fiber and
     also is absorbed in graphite particles at the bottom of

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the hair duct. Photons D and E are depicted as being absorbed in skin tissue.

             Another approach would consist of the following
      steps:
5   1.   Waxing;
           2.   Topical lotion;
           3.   First explosion phase;
           4.   Clean skin with mineral oil;
           5.   Apply mineral oil and massage into ducts;
10   6.   First cooking phase with skin cooling;
           7.   Second explosion phase;
           8.   Repeat step 5;
           9.   Second cooking phase with skin cooling; and
           10.   Clean up.
15   Steps 6 and 7 helps clean out and open up the upper
      portions of the hair duct to permit a cleaner and wider
      passage for photons through the mineral oil filled hair
      duct.

VARIATIONS

20   Persons skilled in the laser-medicine art will
      recognize that many other light source-contaminant
      combinations could be used to practice this invention.
      The important attributes of the combinations are:
             1)   The light source must penetrate skin tissue,
25   at least for the cooking phase;
             2)   The contaminant should be capable of being
      infiltrated in significant quantities into the hair
      ducts;
             3)   The contaminant must be very highly
30   absorptive of energy at the wavelength of the beam and
      capable of being exploded with short high power pulse
      illumination; and

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4)   The process includes at least two distinct
phases: a) an explosion phase to distribute the particles
in the hair ducts and b) a cooking step during which the
skin is cooled and heat energy is applied via the
5 contaminant without substantial fragmentation or
vaporization of the contaminant.

In addition, a clean up phase is highly desirable
in which contaminant remaining in the duct after the
cooking phase is vaporized and/or further fragmented into
10 smaller particles by short pulses of light.

The contaminant (e.g., graphite) vaporizes at a
very high temperature and during the illumination period
of the explosion phase absorbs enough energy to partially
vaporize. These circumstances permit the contaminant to
15 transfer high temperature heat to skin tissue and also to
provide an explosive force to distribute light absorbing
contaminant to the bottom of the hair duct. Ultimate
vaporization and breaking into small parts of the
contaminant during the clean up phase also serves the
20 useful function of removing most of the contaminant from
the duct during the treatment process. Fracturing the
contaminant into ever smaller particles is also a
satisfactory process of effectively removing the
particles. This is because small particles become
25 invisible after a few fractures and once they are reduced
to a small fraction of a micron the body's immune system
can remove them.

Although particle size is not critical, the
particles must be small enough to infiltrate the hair
30 ducts and they should be large enough to absorb the
photons. Preferred sizes are preferably in the range of
0.5 microns to about 5 microns. With illumination that
penetrates skin tissue about 0.5 cm, no more than about
60 J/cm2 can be added without general overheating of the
35 skin tissue unless a portion of the heat is dissipated.

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This overheating can be avoided by applying the heat in
increments allowing the skin to cool naturally between
illuminations. Another approach is to artificially cool
the surface of the skin either prior or during the
5 illumination or both prior to and during the
illumination. We have performed tests using cold air, ice
and canned nitrogen to cool the surface of the skin. We
recommend topical cooling to be used only when natural
cooling is not effective. Cooling the surface of the skin
10 may interfere with nerve sensors in the skin, which
provide a natural alarm function to prevent unintended
damage to the skin.

　　　　Many contaminants other than graphite particles in
mineral oil may be used. Applicants have tested acrylic
15 tattoo inks which have been approved by FDA for tattoo
use. Black and blue tattoo inks marketed by Spaulding and
Rogers appear to work well with a Nd:YAG laser operating
at 1 Hz, 1.06 micron with an energy density of about 3
J/cm^2. We had less success with other colors.

20 　　　　It is not necessary to remove the hairs prior to
illumination. FIG. 3B depicts an illumination phase with
the hair shaft remaining in the duct as compared to FIG.
3A where the hair has been removed. The three preferred
illumination phases are as described above. The results
25 are not as good with the hair in place during the process
since the quantity of graphite which can be loaded into
the duct is greatly reduced.

　　　　Pulse durations other than those described above
may be used. For example, we have performed preliminary
30 tests with 2-ns pulses for the explosion phase. These
pulses appear to provide greater explosions but it may be
necessary to reduce the energy per pulse to avoid general
damage to skin tissue.

　　　　We have discovered that better transmission
35 through the skin can be achieved by stretching the skin.

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This also helps keep the ducts open which is important
when utilizing the embodiment in which photons are
transmitted down the hair duct through mineral oil.
Pressing the skin reduces the distance between the skin
5 surface and the hair root and could thereby result in
more photons being absorbed in the lower regions of the
duct.

Illumination during the cooking phase can be
affected by any of a wide variety of illumination
10 sources, and with different pulses, from very short
nanosecond pulses to much longer pulses, or even a
continuous beam for periods of a few seconds. The
objective is to impact as much energy as feasible to the
graphite particles without causing general overheating of
15 skin tissue. The laser could be controlled with a
microprocessor to automatically provide a Q-switched
beam, then a non-Q-switched beam followed by a Q-switched
beam. Such a system could be useful in conjunction with
automated scanning.

20   Another embodiment of this invention is to utilize
for the cooking phase a laser pulse which vaporizes a
very small percentage (such as 1%) of the graphite in the
duct with each pulse. This would permit several hundred
pulses before the quantity of graphite is reduced to the
25 point of ineffectiveness. At that point a few 2 J/cm^2
pulses could be applied to vaporize most of the
remainder.

SKIN COOLING

Skin cooling may be used for safely conducting
30 dermatological and cosmetic treatments, such as hair
removal, and other skin treatments in general, such as
laser-based skin peeling, skin rejuvenation, treating
port wine stains, or subdermal skin treatments. Although
examples given here for the purpose of teaching how to
35 make and use the cooling-related invention for laser-

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assisted skin treatments are primarily concerned with
hair removal, and U.S. Patent 5,423,803, which is
incorporated herein by reference, relates to laser-based
skin peeling, one skilled in the art will readily
5   appreciate that the invention is useful for any type of
skin treatment in which lasers are used, including, for
example, treatment of spider veins, port wine stains, and
such ailments.

        The coolant is a low boiling point liquid
10 refrigerant which, when applied, quickly evaporates, thus
cooling the surface 50 to 70 degrees Celsius below
ambient skin temperature. The coolant is applied as a
high speed jet, therefore, the heat transfer coefficient
between the liquid and the tissue surface is extremely
15 high, resulting in efficient cooling of the immediate
surface and a thin layer below. Surface temperatures
remain low enough to maintain epidermal viability, while
subsurface tissue temperatures are raised sufficiently
high enough by the laser illumination to produce a
20 spatially confined wound to the papillary dermis. The end
goal of this modality is to induce a strong wound healing
response which results in long term synthesis of new
collagen and extracellular matrix material, thus,
reducing wrinkles.
25   In one embodiment, approximately 0 degree C air
blown is on the skin surface being illuminated with
sufficient force to assure turbulent flow. The
turbulence is believed to facilitate evaporization of
liquid droplets from the immediate area surrounding the
30 skin.

        The methods of cooling available with the cooling
systems discussed below with reference to the example of
Fig. 7 provide a specific application of the cooling
system of this invention, and demonstrate a general
35 method of cooling for safely allowing laser energy to be

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used on the skin. One safety concern related to laser-
assisted skin treatment is how to protect the epidermis
when targeting biological tissue below the epidermis,
e.g., the dermis or hair follicles.   The general method
5 demonstrated by the example of Fig. 7 involves the step
of first applying one or more laser pulses to heat the
epidermis and dermis to near the pain threshold (about 50
C), then applying a cooling medium to the epidermis.
These steps are followed by the steps of cyclically
10 applying laser pulses and cooling medium so that the
target tissue is incrementally heated while the
temperature profile of the epidermis is kept cool enough
to prevent damage and/or significant pain. The above-
described cooling method enables the papillar and
15 subdermal tissue to be heated sufficiently for treatment
while protecting the epidermis.

         While not wishing to be limited to any particular
theory, the invention is believed to be based on a
critical recognition that laser light may readily
20 penetrate through the skin to generate heat below, while
cooling may be readily applied only to the epidermis.
By taking advantage of this principle, not only may the
epidermis be protected from heat while heating tissue
below, but additionally the epidermis may be protected
25 from excessive cooling because the transfer of laser-
generated heat from tissue below to the cooled skin
above, maintains a desired safe uniform temperature
profile.

         Fig. 8 shows an experimental cooling system 23
30 built and successfully tested for practicing cooling,
including capability for implementing the method
described above. System 23 includes an air compressor 20
providing compressed air flow through a 3/8-inch 100-foot
tube 22 coiled in a large container filled with ice
35 water. Cooled air is released through end 25, preferably

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to a handpiece 27 (described in detail below, with
reference to Fig. 9) which then releases it to a target
region of skin 30. The inventors have also conducted hair
removal experiments cooling with ice applied to the skin
5 and with canned nitrogen. Much more sophisticated
systems may be used to cool the skin, including using
nitrogen or a cryogen-based refrigerant, discussed in
more detail below.

          Referring again to Fig. 8, the laser beam (not
10 shown) delivered from laser 26 is delivered through
optical delivery system 28, such delivery systems being
well known in the art. The light, preferably delivered
through handpiece 27, illuminates the target skin region
30 in a timed relationship with cooling air from tube 22.

15   Referring to Fig. 9, system 23 includes a
handpiece 27 for delivering both the cooling medium and
laser beam. The hand-piece 27 may be coupled with laser
system 26 (Fig. 8), directly or indirectly through light-
delivery system 28 for delivery of laser beam 60 to the
20 target region of skin 30. The hand piece may also be
coupled to one or more cooling-delivery tubes 25a for
delivering spray stream 29 of a cold medium to the same
target region of skin. The handpiece may also be used
with more sophisticated systems and may be varied if
25 needed to add other functions.

          The handpiece includes an optical portion 31, a
cooling portion 33 that includes coupling piece 37.
Optical portion 31 includes one or more well-known laser-
matched optical lens (not shown) in an optical cavity
30 (also not shown) for delivering laser beam 60 to the
target skin region 30. The optical portion is provided
with a tubular coupling piece 34 which fits into bore 36
of cooling portion 33, which includes one or more nozzles
33 for passing cooling spray 29 from tubes 25a to the

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target skin region 30. The hand-piece 27 should be spaced
a predetermined distance d from the skin.   Preferably
this distance should not exceed 85 millimeters.

        Fig. 10 shows a cryogen-based evaporative cooling
5 system 23b which may be also be used to provide effective
cooling laser-based skin treatment. Cryogens are non-
toxic, fluoroethane-based refrigerants that have been
approved as replacements for chlorofluorcarbons. A well-
known Cryogen known as Refrigerant 134a, is composed of
10 100% Tetrafluorothane, and it is a good choice because it
has a boiling point of 126 degrees C and a vapor pressure
of 72 psia at 18 degrees C.

        The cryogen may be administered from storage 40,
which may include an optional subcooler, and then sprayed
15 29b via a fluid atomizing orifice 42 which may be a
nozzle injector and that is maintained on handpiece 27 at
the fixed distance d above the skin surface 30.
Handpiece 27 is similar to handpiece 27b, and is shown on
an exaggerated scale for the sake of clarifying the
20 handpiece components.   Storage 40 may include a
compressor and other necessary known mechanical devices
(not shown) for storing, subcooling, and delivering the
cryogen. The Cryogen may be atomized in controlled
spurts of fluid 27b lasting a predetermined time, e.g,
25 about 40 milliseconds to provide cooling of the type
called for in the example shown in FIG. 7.

        Pressurized fluid atomizers may be used or
alternatively spinner-type atomizers could produce a
stream of atomized fluid particles whose diameters can be
30 controlled by adjusting the spin speed. The simplest
type of atomizer is probably a very long micro-diameter
filament tube, which can be controlled simply by opening
a micro-tube at appropriate times during treatment, as
described below with reference to FIG. 10.

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Referring again to Fig. 10, cooling system 23b comprises a cryogen-based evaporative cooling system that is an effective means of protecting the skin during laser treatments, including hair removal and skin peeling
5 treatments. Evaporative cooling is believed to be the primary mode of heat transfer for safe cooling of the skin surface while using system 23b. The atomization of the cryogen and the adiabatic absorption of some of the liquid into the air directly above the treated area also
10 results in the sensible cooling of that air to between about -60 to -50 °C, which also assists in the cooling of the treated area.

It is believed that the expansion cooling of the stream of spray 29 is due to de-pressurization of the
15 fluid as it exits nozzle 42 mounted to coupling piece 37. Nozzle 42 preferably receives its input from distribution manifold 39. Throttling, or de-pressurization, of the pressured cryogen, or liquid cooling fluid, to atmospheric pressure is a thermodynamic phenomenon that
20 results in the cooling of the exiting fluid as it separates in a two-phase (vapor and liquid) mixture. It is believed further that the skin surface or epidermal layer 30 is sub-cooled via evaporative cooling of the preferably atomized cryogen liquid that reaches the
25 surface. This evaporative heat transfer may be enhanced by maintaining an impingement of the atomized liquid stream that will breakup any formation of a fluid vapor layer above the surface, and in particular such a vapor layer having low thermo-conductive properties. By
30 maintaining a cold skin surface and surrounding environment, the dissipation of laser-generated heat from the epidermal sub-layers via conduction heat transfer will be enhanced.

It is believed that enveloping the affected skin
35 surface by a continuous stream of dry, sub-cooled air 34

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will maintain desired thermal effects for the skin and
the surrounding environment.   An air curtain 34 is
applied over the treated surface 30 through delivery
orifice 43, which also may be a nozzle, and which like
5   delivery orifice or nozzle 42 also receives its input
from distribution manifold 39 coupled to respective feed
tubes.   Delivery tubes 43t and 42t delivering the dry air
spray and cryogen, respectively, to a manifold 37 for
respective delivery to nozzles 43 and 42.   Laser beam 60,
10   dry air spray 29b, and cryogen spray 60 are delivered in
a relatively-timed fashion to maintain a desired
temperature profile on target region of skin 30.

The dry air spray 44 forming the air curtain over
the treated surface is composed of circulating dry air
15   that is delivered from air circulation device 45 which
preferably includes a drying desiccant material 47.   The
dry air captured in the cryogenic spray stream 29 is
cooled by the evaporation of some of the fluid particles
exiting the atomizer.   The circulating air insures that
20   the cryogen that has been evaporated at the skin surface
by the laser-generated heat is immediately removed from
the treated surface.

Referring also again to FIG. 9, this removal may
be facilitated by the use of a distribution of small
25   vacuum tubes 101 that evacuate the treated surface.   This
may also serve to recover the cryogen via a liquid
coalescer (not shown) if required or desired.   The vacuum
tubes 101 also provide a necessary fixed height
adjustment that should be maintained between the nozzle
30   42 and the treated surface.   Maintaining a constant,
predetermined height of the nozzle over the treated
surface additionally ensures that the laser beam will be
properly focused ont he treated surface.   An air
collection fixture or "hood" (not shown) and mini-
35   induction blower (also not shown) could also be

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incorporated into the integrated design to help recapture the evaporated cryogen fluid rather than allowing it to be released into the air.

The atomizing fluid orifice or nozzle 42 may be a 5 pressurized fluid injector, or may be a spinning disk-type atomizer, that in a simple form is a very small diameter, but relatively long, filament tube in which flow has been restricted to establish a desired flow rate.

10 It is believed that a pressurized fluid atomizer will instantly produce a cooler, two-phase fluid stream with about 70% of the fluid in the liquid phase and available for evaporative cooling. Controlling the distribution of the atomized fluid particles and removing 15 the ineffective vapor phase of the expanding cryogen will probably improve the overall effectiveness of the evaporative cooling method by at least allowing more controlled predictable responses.

The spinning disk-type atomizer is more 20 complicated than a pressurized fluid injector but provides an advantage of producing a similar stream of atomized fluid particles having particles of a size which can be controlled by simply adjusting the atomizer's spinning speed (rotations per minute). Further a 25 spinning disk-type atomizer may allow for increasing the amount of liquid phase cryogen available for evaporative cooling. It is believed that as the cryogen fluid expands through the nozzle or valve orifice it can be made to impinge on a rotary disk that absorbs energy from 30 the cryogen fluid. This energy removal is believed to increase the amount of liquid fluid percentage in the expanding fluid steam. Thus, the typical 70% fluid amount may be increased to 75%, for example, to provide more liquid at the surface of the skin, and thus faster 35 evaporative cooling.

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The nozzles 42 and 43 can be paired in a radially-
disposed fashion on coupling piece 37 as shown in the
plan (bottom) view of Fig. 11. Of course, the nozzles
may be disposed in a number of fashions other than those
5   shown. The schematic view of Fig. 10 shows only one of
each nozzle type, with each respective pair-mate not
being visible.

Fig. 12 shows an alternative arrangement of the
nozzle 42 and 43 relative to coupling piece 37, wherein
10 the orifice 43o of nozzle 43 is larger than the orifice
42o of nozzle 42 which provides an alternative way to
ensure that the cryogen spray is enveloped in a dry air
curtain. Of course, one skilled in the art will
recognize that the geometric relationship of the nozzles
15 may be varied from that shown without deviating from the
spirit or scope of the invention.

Referring again to Fig. 10, a temperature detector
50, which in a preferred embodiment is well-known
infrared detector is used in combination with temperature
20 control system which may be a well-known digital
computer. The skin temperature monitoring may also be
performed by thermocouples or resistance temperature
detectors that are wired to the underside of a vacuum
tubes 101 (FIG. 9) and thus may be in direct contact with
25 the treated surface.

The control system 52 serves as a safety-switch to
prevent overheating the skin to dangerous levels. The
temperature control system 52 may be used to shut off the
laser or otherwise adjust the laser energy-level and/or
30 by applying coolant. Further, the temperature detector
40 and control system 52 can be used to monitor and react
to dangerously low skin temperature as well.

The systems described above can be integrated into
a light-weight small hand-held instrument 27b that
35 includes the temperature detector 50 communicatively-

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coupled to a control system, an optical cavity for
passing the laser-beam to the skin, and orifices for
delivering cryogenic and dry air sprays. The relatively
timed fashion delivery of the laser and cryogenic and dry
5   air sprays may be controlled by a the temperature control
system which preferably has computing capability for
communicating with the laser for digital control and to
the dry air and cryogen systems (e.g. by opening and
closing switches and activating valves).
10   Fig. 14 shows another arrangement of cryogen
delivery nozzles 42c in which two features are available.
The nozzles are arranged so that their respective stream
paths cross, creating turbulence at the confluence 61.
This turbulence causes liquid drops to evaporate in the
15   turbulent flow so liquid does not condense on the skin
surface. Sufficient turbulence may obviate the need for
dry air, or the dry air may be used in a supplemental
fashion.

        The various arrangements discussed above, allow a
20   desired temperature distribution to be obtained and then
maintained by careful arrangement and selection of spray
orifices and spray ingredients, and careful
synchronization of the laser with cooling. In general the
inventors have recognized that pressure, temperature, and
25   nozzle geometry, including orifice geometry are variables
that may be manipulated to achieve a desired uniform
temperature profile. For example, referring again to
Fig. 14, a desired temperature profile may be maintained
along lateral dimension "l" and through depth d_t of the
30   skin target region 30. Further, by implementing the
teachings of this invention a desired temperature profile
may be maintained all through the volume defined by the
area bounded by skin of length "l" with depth d_t and
width "w." These benefits can arise from employing a
35   temperature control system, effectively minimizing or

- 37 -

eliminating condensation, and controlling the variables
described above with reference to the nozzle geometry,
and temperature and pressure of the sprays" Moreover, a
uniform temperature profile may be maintained along the
5 same volume, such that approximately only one constant
temperature can be measured anywhere in the volume.

In recognition of the importance of being able to
manipulate pressure, a secondary pressure vessel 66 shown
in Fig. 13 and joined by a coupler such as valve 64 to
10 cryogen storage and feed system 40 which includes primary
pressure vessel 62. Typically, cryogens stored and are
provided at a set nominal pressure (e.g. 72 psia), but
the introduction of the secondary pressure vessel 66
allows for the cryogen spray 29 to be delivered at a
15 desired pressure for achieving the desired temperature
profile.

NONABLATIVE LASER TREATMENT OF FACIAL RHYTIDES

Another use of this invention is in combination
with an Er:glass laser system for the nonablative laser
20 treatment of facial rhytides. The laser operates at a
wavelength of 1.54 μm and is preferably delivered to the
skin using a fiberoptic handpiece. At this wavelength,
the primary tissue chromophore for absorbing the laser
energy is water, which has an absorption coefficient of
25 approximately 10 cm^{-1}. The laser delivers a sequence of
pulses of light at less than 10 msec duration, and at a
50 Hz repetition frequency and pulse radiant exposures up
to 40 J/cm^2.

A cryogenic spray cooling device is used to
30 preferentially cool the epidermis prior to, and
immediately following, laser heating. The device uses a
multiple nozzle architecture to deliver coolant to the
skin surface. The nozzles may be temporally fired in a
series of rapid pulses with an appropriate duty cycle
35 which allows the user to tailor a specific temperature

- 38 -

depth profile while maintaining an acceptable surface temperature.

A multiple nozzle laser handpiece capable of spraying a fluid coolant in a temporal sequence through
5   the multiple nozzles is shown in FIGS. 15-20. Referring first to Fig. 15, the handpiece 110 includes three cryogenic nozzles 112 at a distal end. The three nozzles 112 are configured to direct a stream or spray of a fluid cryogen in lines that intersect at a preselected working
10   from a skin surface. Handpiece 110 also includes a thermally insulating housing 114.

Referring now also to Figs. 16-20, each of nozzles 112 are supported by a nozzle fitting 116 that is attached to an aluminum block manifold 118. Manifold 118
15   includes forward coolant channels 120, each connecting between a respective nozzle fitting 116 and an outlet of a respective solenoid valve 122. An inlet of each solenoid valve 122 is coupled through a respective rear coolant channel 124 an annular channel 126 at a rear end
20   of manifold 118. Annular channel 126 connects to an inlet channel 128, which is coupled through a rear coolant fitting 130 to a coolant inlet tube 132. Tube 132 is coupled to a source of liquid refrigerant, such as Refrigerant 134a, which is provided under pressure.
25   Thus, each of solenoid valves 122 and nozzles 112 are fed through a common coolant line 132 connecting to handpiece 110. Each of solenoid valves 122 also has connected to it respective electrical control signal wires 134, only some of which are shown in the drawing (See Figs. 17 and
30   19).

In the described embodiment, solenoid valves 122 are provided by SMC Pneumatics, part no. VQ110-5L-M5. These valves are capable of opening and closing is a period of about 2-10 msec. They are operated in a
35   temporal sequence, each with a duty cycle that is short

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enough so that its operation is not significantly
impaired by cooling. The major benefit of operating
valves 122 in a temporal sequence is that short bursts of
coolant can be directed at the skin in a rapid sequence
5 not possible using a single valve. the short, rapid
bursts avoids pooling of the coolant on the skin. Pooled
cold refrigerant on the skin can cause water to condense
from surrounding air and ice crystals to form. Ice
crystals or liquid water forming on the skin can absorb a
10 significant amount of the energy from the laser beam, and
can also distort the focus of the laser beam. Thus, by
avoiding pooling on the skin, the negative effects of
water condensation and ice formation can be avoided.
     Annular channel 126 has a rear wall provided by a
15 forward side of a circular washer 136. Resilient o-rings
138, 140, which are made of neoprene, provide seals
between manifold 118 and washer 136. Coupled to a rear
side of washer 136 is a lens holder assembly 142. A
fiber optic cable 144 is coupled to lens holder assembly
20 142 through a fiber optic connector 146, which in the
described embodiment is an SMA 905 connector. Fiber
optic cable 144 couples at its other end to a light
source, such as an Er:glass laser or a Nd:YAG laser as
described above. Lens holder assembly 142 is screwed to
25 manifold 118 with screws 148 that pass through apertures
in washer 136. There is another neoprene o-ring 150
between washer 136 and lens holder assembly 142, allowing
adjustment of a tilt angle alignment of lens holder
assembly 142 relative to manifold 118 by variably
30 tightening screws 148. O-ring 150 also provides
resiliency for compensating for vibrations and the like.
     Lens holder assembly 142 includes a housing 152
providing a central chamber. A spherical bi-convex lens
154 is held in place in housing 152 chamber between an
35 outer lens holding ring 156 and an inner lens holding

ring 158. Outer lens holding ring 156 has a threaded
outer surface to screw a threaded inner wall of housing
152. Inner lens holding ring 158 also has a threaded
outer surface to screw into a threaded inner surface of
5 outer lens holding ring 156 with lens 154 in between. A
spanner wrench 160, shown in Fig. 18, fits in slots 162
provided in housing 152 to adjust the longitudinal
position of outer lens holding ring 156 within housing
152, and thereby the position of lens 154. By this
10 means, the focal position of a laser beam 166 passing
through lens 154 is be adjusted. The lens is locked with
a set screw 178. The laser beam 166 passes through a
central passageway 170 in manifold 118.

A stand-off 164 is provided at the forward end of
15 handpiece 110. By keeping a forward tip of stand-off 164
touching the surface of a subject's skin, the operator
can be assured that the laser beam 166 is focused to the
proper depth and the coolant is directed to a spot on the
skin illuminated by the laser beam 166. In the
20 illustrated embodiment, stand-off 164 is held by a flange
168 attached to nozzles 112. In another embodiment (not
shown) a stand-off is attached to a ring that screws onto
a forward end of housing 114.

Handpiece 110 also includes a temperature sensor
25 172 held in manifold 118. This can be provided, for
example, by Eltec Co. part no. 40612. A plano-convex
lens 174 directs infrared radiation from the skin onto a
receiving surface of sensor 172. Signal wires 176 extend
through a cable from the rear of sensor 172.

30 Referring now to Fig. 21, a coolant fluid system
includes a tank 180 holding the coolant 182 in liquid
form under pressure. Pressure is maintained by a
temperature controller 184 that is coupled to a tank
temperature sensor 186 and a heater 188 wrapped around
35 tank 180. The liquid level is monitored with a tank

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weight sensor 190. A pressure transducer 192 monitors
pressure in tank 180 and provides a pressure signal to a
pressure alarm controller 194. If the pressure exceeds a
set value, pressure alarm controller shuts off power
5 passing through a first solid state switch 196.
Similarly, temperature controller 184 will shut off power
passing through a second solid state switch 198 in series
with the first switch 196 if the temperature in tank 180
exceeds a set value.

10   Precise timing of the laser heating and cooling
pulses may be controlled by computer. Key modality
parameters may be varied including number of cooling
pulses, cooling duration and duty cycle time, temporal
delay between heating and cooling pulses, and radiant
15 laser exposure. In addition to providing timing signals,
such a computer may also monitor various cooling safety
interlocks including; optical pyrometer signal to measure
surface temperature, flow sensors to insure cryogen
delivery and laser control signals to insure laser
20 delivery.

        Liquid cryogen is supplied to handpiece at about
90 psig, which is sufficient to prevent boiling in the
supply line from the tank to the handpiece. the time
between pulses for each valve can be varied between 1 and
25 20 msec. High heat transfer rates over a short time
interval are achieved due to the high velocity of the jet
on the surface producing a thin boundary layer, and as a
result of a sufficiently high transfer coefficient
between the surface and the liquid/gas stream flowing
30 across it.

        Referring now to Fig. 22, at the center of a jet
200 the velocities are high, so the heat transfer leads
to rapid cooling. Further from the center the velocities
slow down, and the boundary layer thickens. If enough
35 fluid flows across the surface the result is a time

- 42 -

interval of low heat transfer rate following the initial
high rate period, with a substantial increase of the time
cooling occurs due to the pooling of the liquid in the
thicker boundary layer. The low heat transfer period

5   will continue until the pooled liquid is evaporated.
Cooling with 5 msec pulses with 5 msec spacing over a 50
msec time period can eliminate the pooling and the low
heat transfer characteristic. A laser treatment for hair
removal, skin peeling, subdermal skin rejuvenation or the

10 like can be carried out as described above with reference
to Fig. 7 with handpiece 110 enabling the use of a
temporal sequence of rapid fire cooling pulses within the
boundaries of each cooling step illustrated.

        Thus, it has been shown that this invention offers
15 cooling methods and devices not available before for
safely maintaining a desired temperature profile of skin
while using a laser-assisted skin treatment, including,
but not limited to, long-term hair removal and skin
peeling.

20   The above-described methods are exemplifications
of preferred embodiments of the inventions and other
possible variations are within its scope. Accordingly,
the invention is limited only by appended claims and
their equivalents.

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CLAIMS

1. A handpiece for laser skin treatment, comprising:

    an optical coupling to an illumination source;

    a focusing system for focusing illumination from

5   the illumination source to a target region of skin;

    a fluid coupling to a coolant fluid source;

    a plurality of valves having inputs in fluid

communication with the coolant fluid source through the

fluid coupling, each valve including an output

10 communicating with a respective nozzle which is arranged

to direct the coolant fluid to the target region of skin,

the valves operating in a temporal sequence.

2.   The handpiece of claim 1, wherein the temporal

sequence is characterized in that no two of the valves

15 are open at the same time.

3.   The handpiece of claim 2, wherein the temporal

sequence is further characterized in that each valve

remains open for a period between about 2-10 msec.

4.   The handpiece of claim 3, wherein the temporal

20 sequence is further characterized in that there is a

period of between about 1-10 msec between the closing of

one valve and the opening of a next valve in the temporal

sequence.
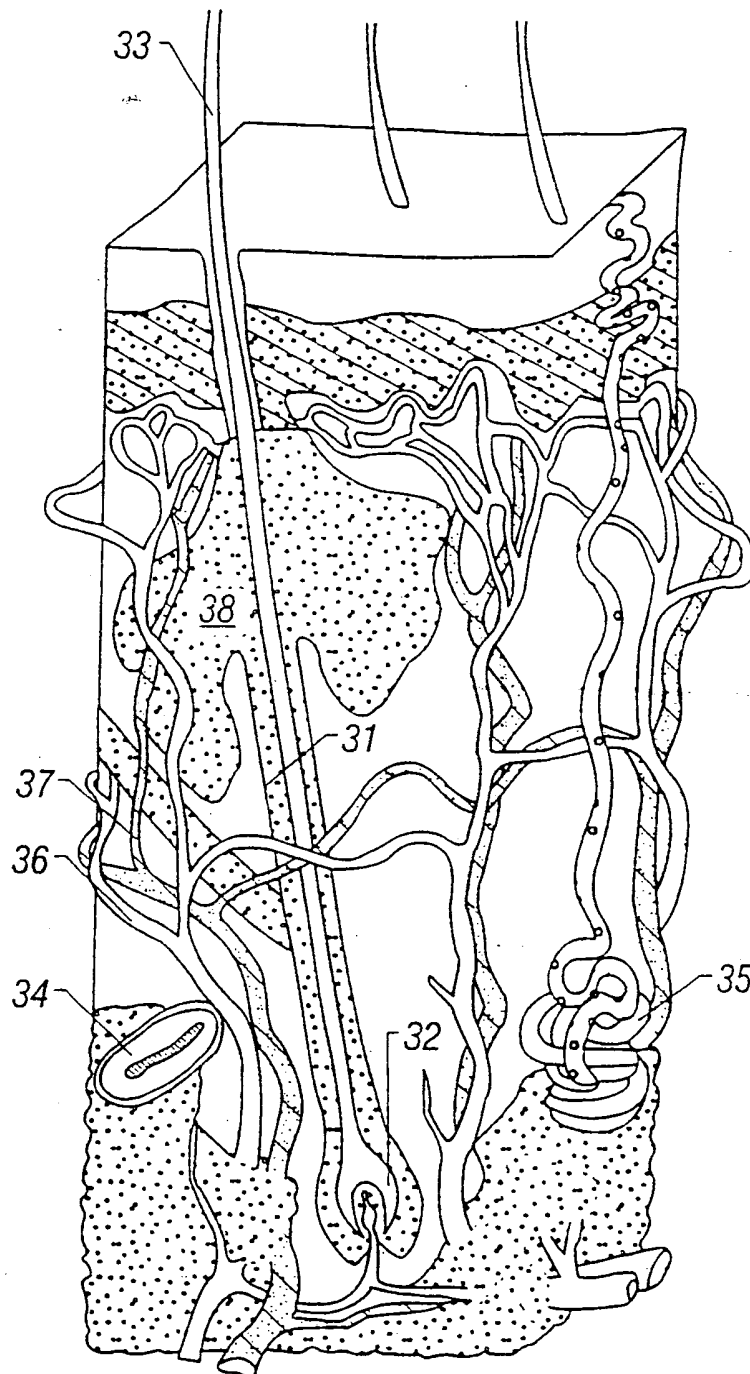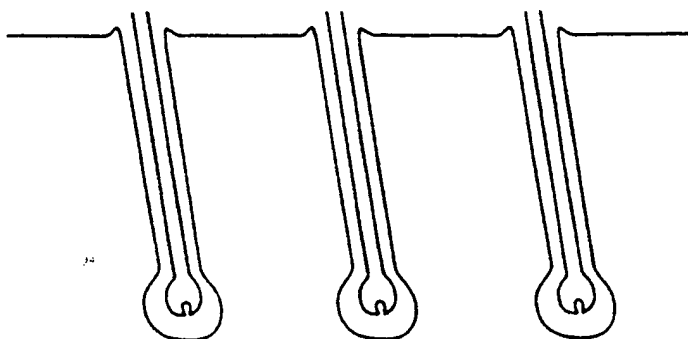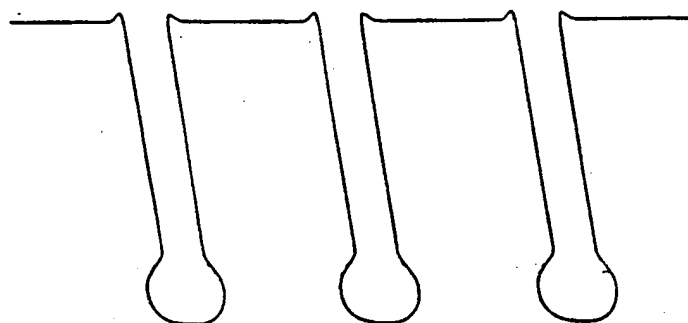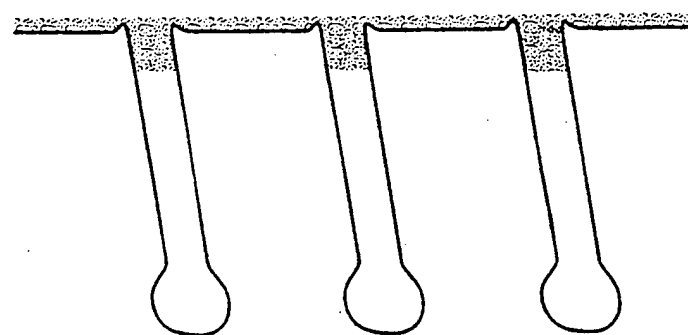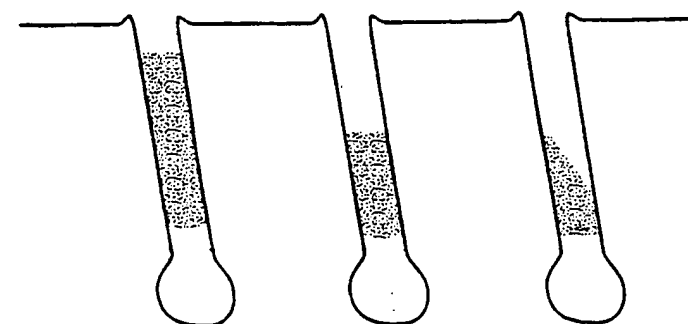
FIG. 1

FIG. 2A

FIG. 2B

FIG. 2C

FIG. 2D
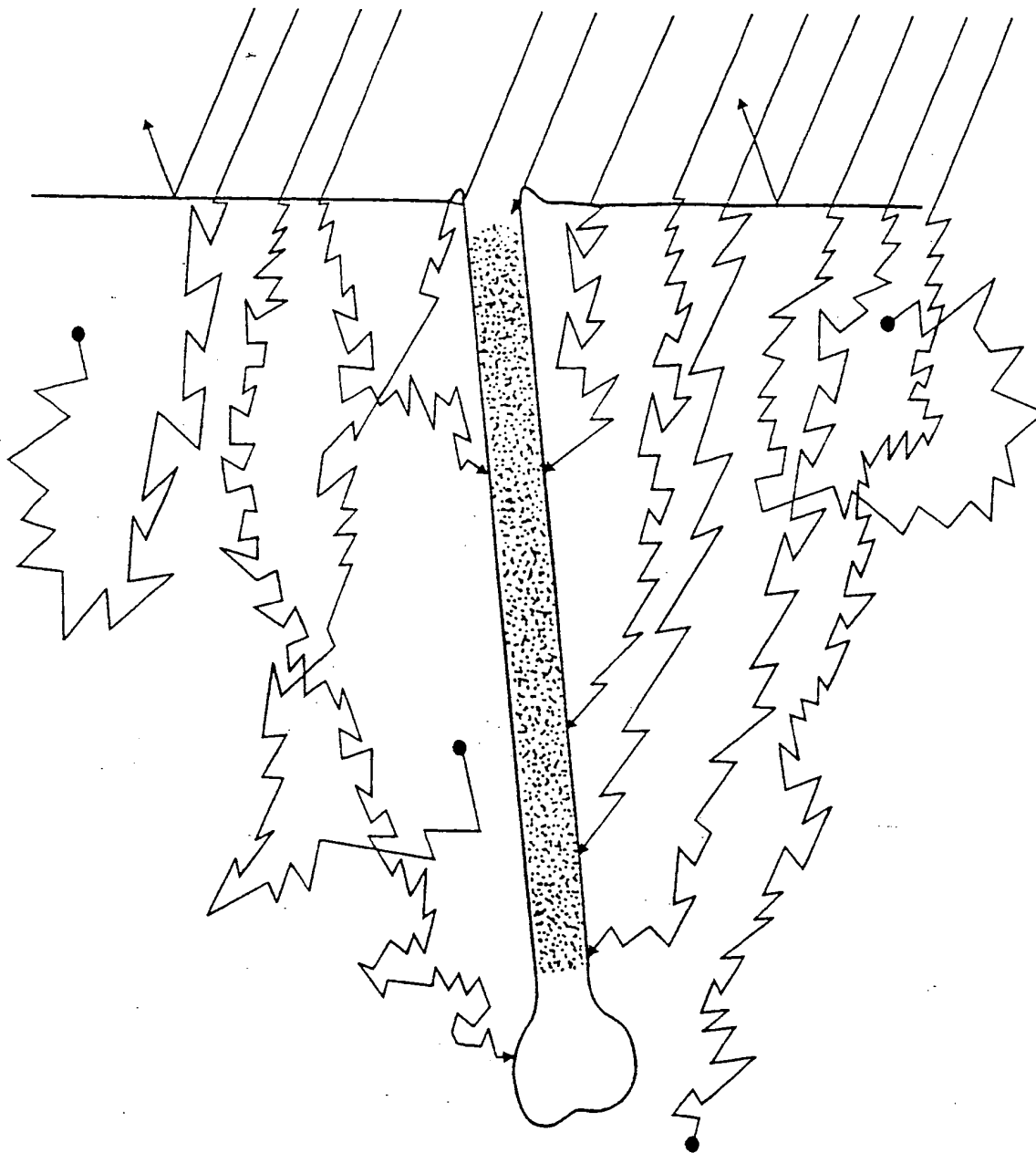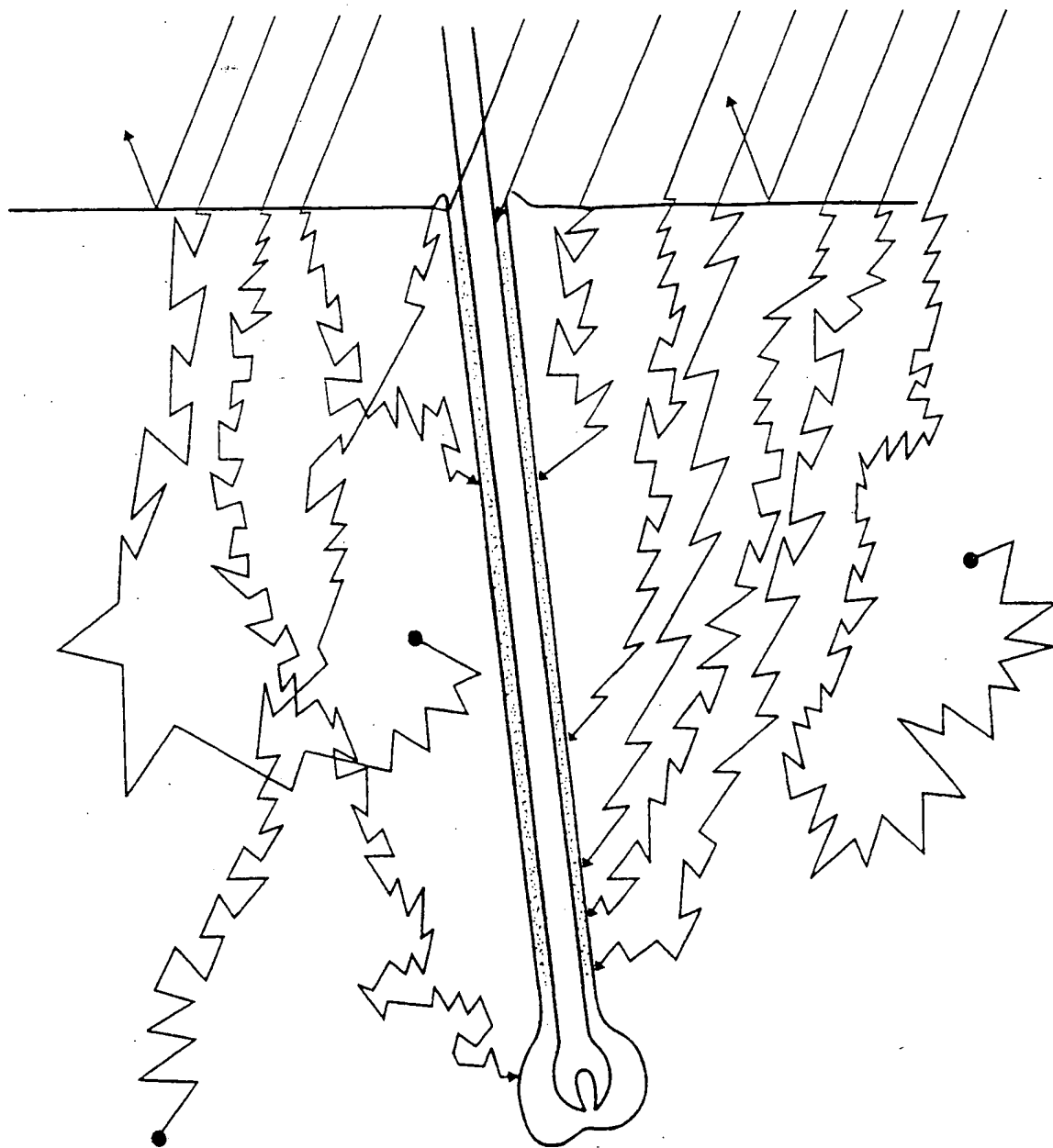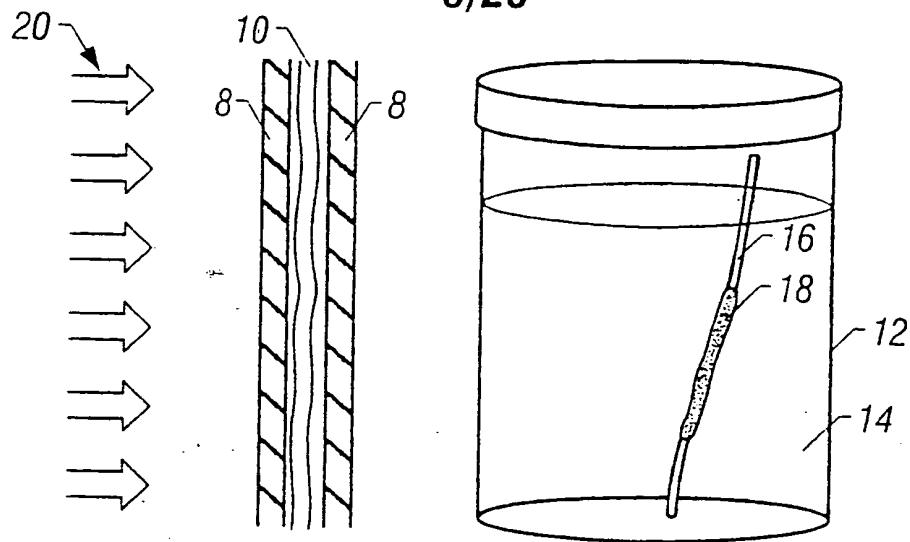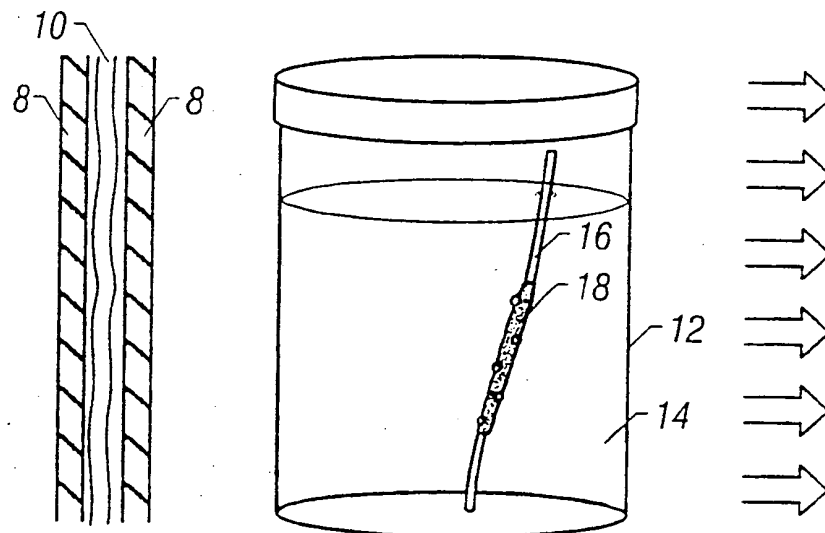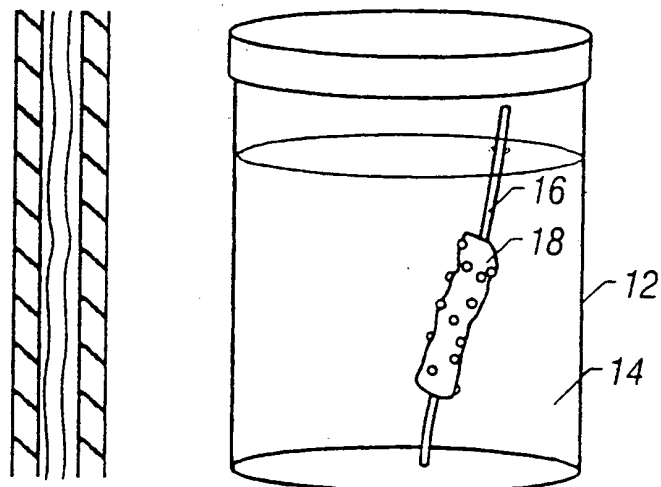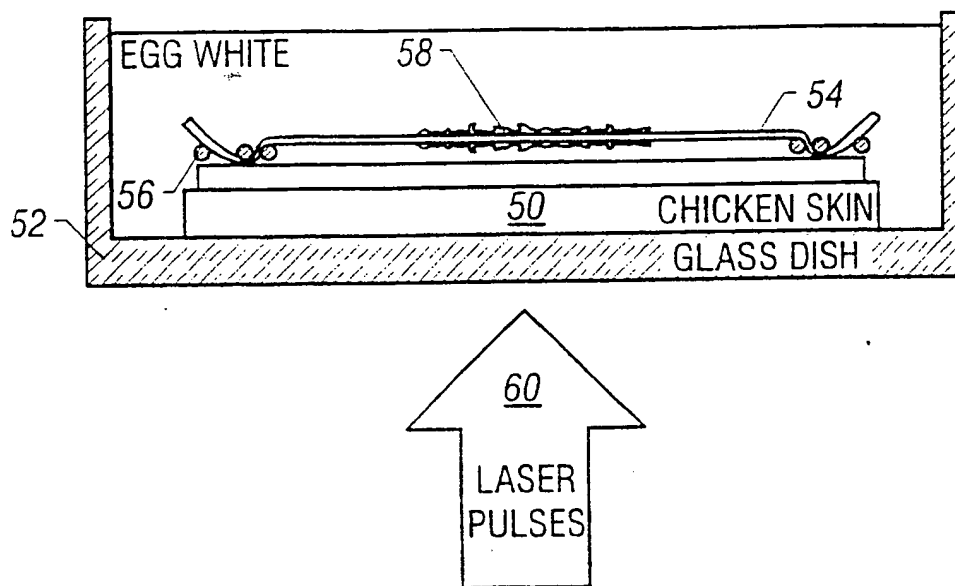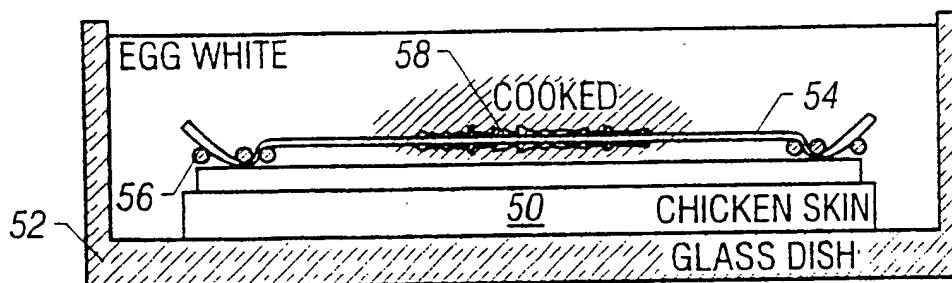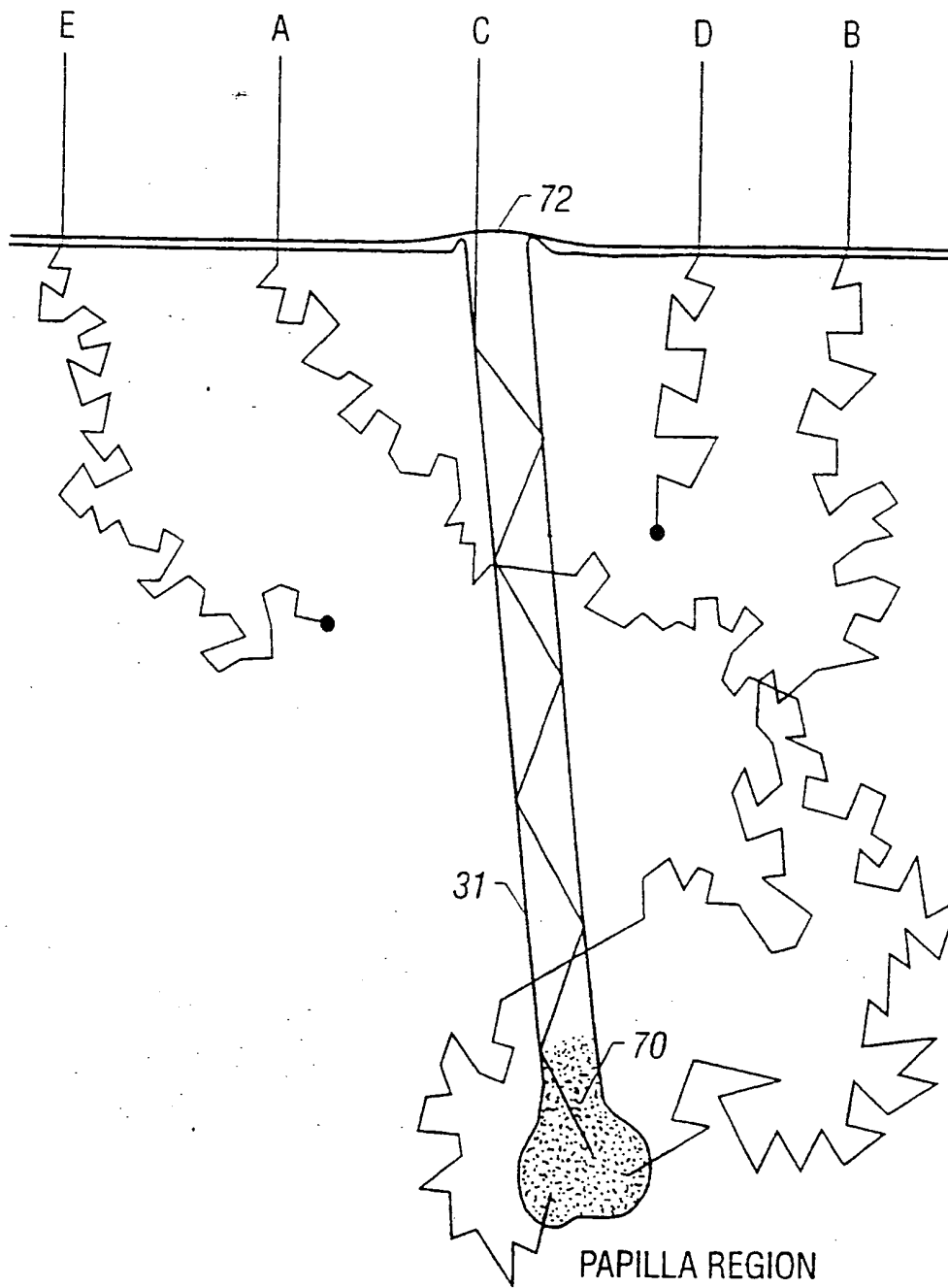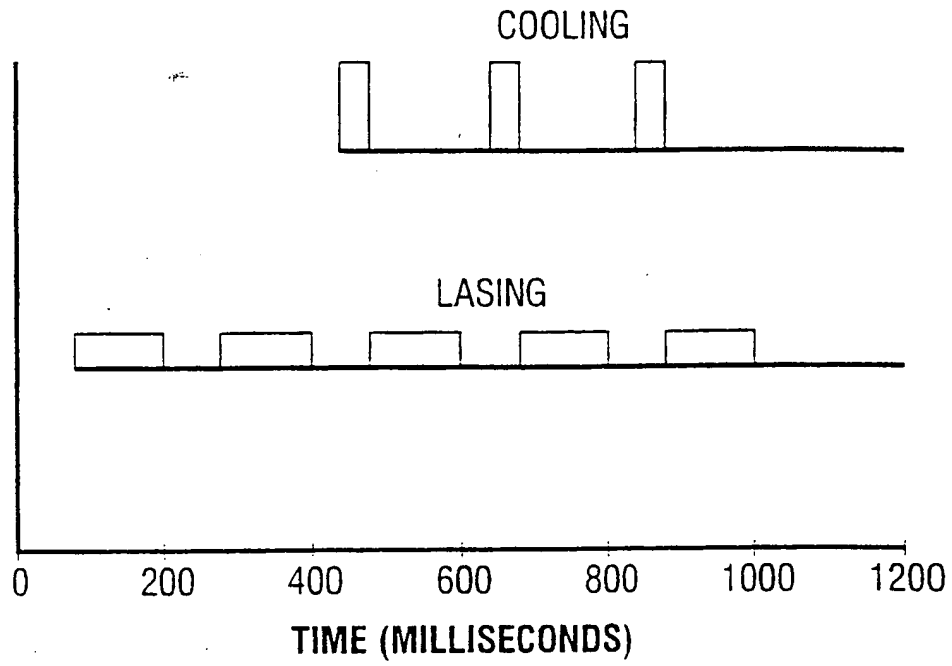
FIG. 3A

FIG. 3B

FIG. 4A

FIG. 4B

FIG. 4C

FIG. 5A

FIG. 5B

PAPILLA REGION

FIG. 6

COOLING

LASING

TIME (MILLISECONDS)

FIG. 7

SKIN

ICE
WATER

COMPRESSOR

LASER

FIG. 8

27

31

34

36

33

25a   25a

101   *37*   101

33   33

29   29
29   29

d

60

TARGET REGION OF SKIN

30
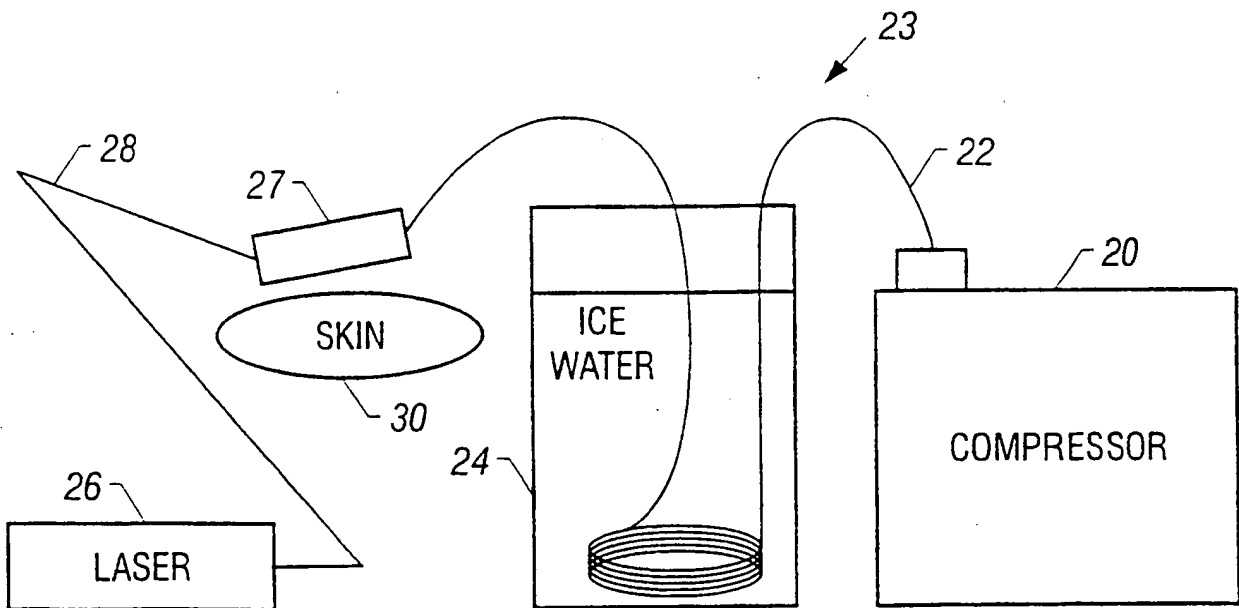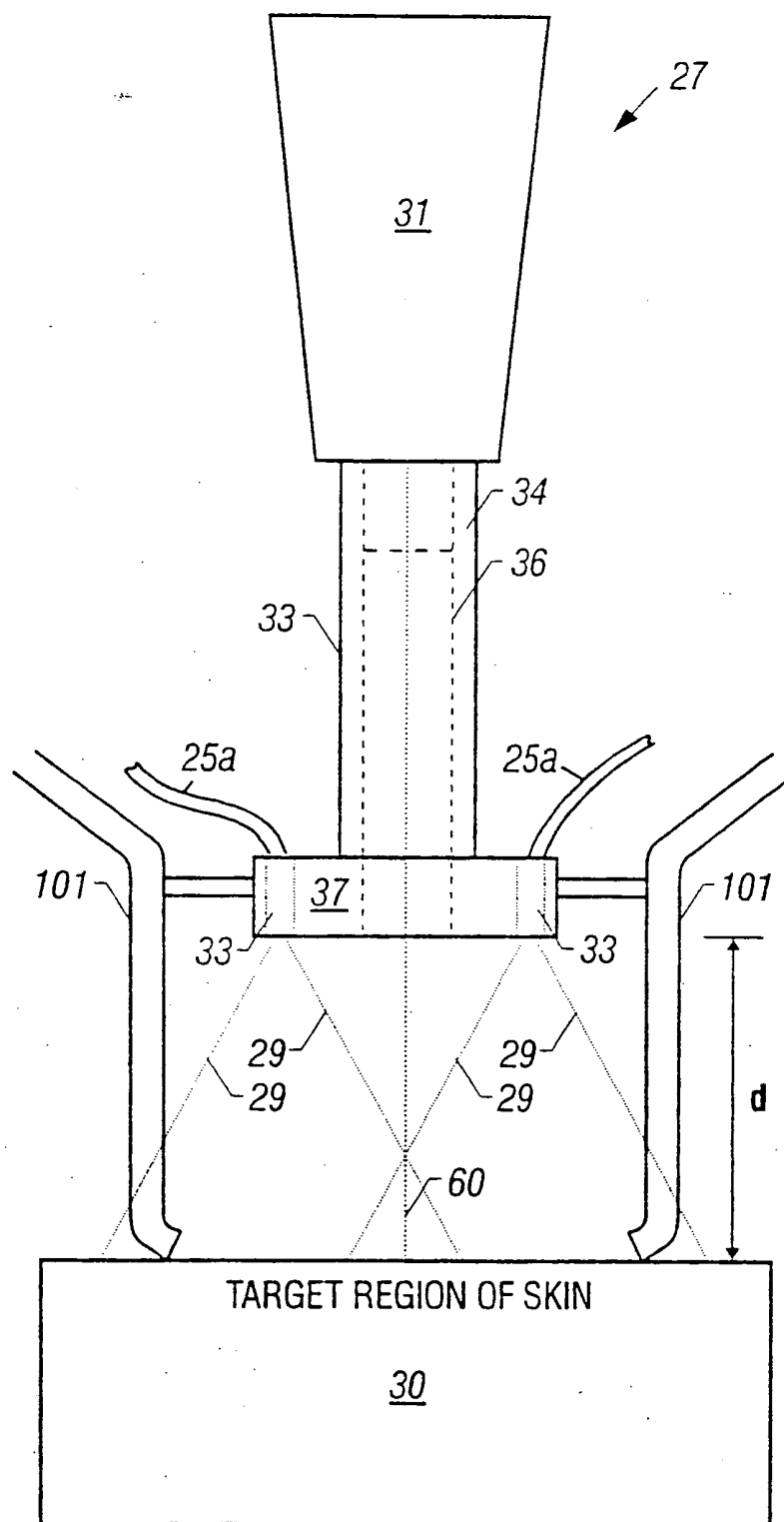
FIG. 9

10/20
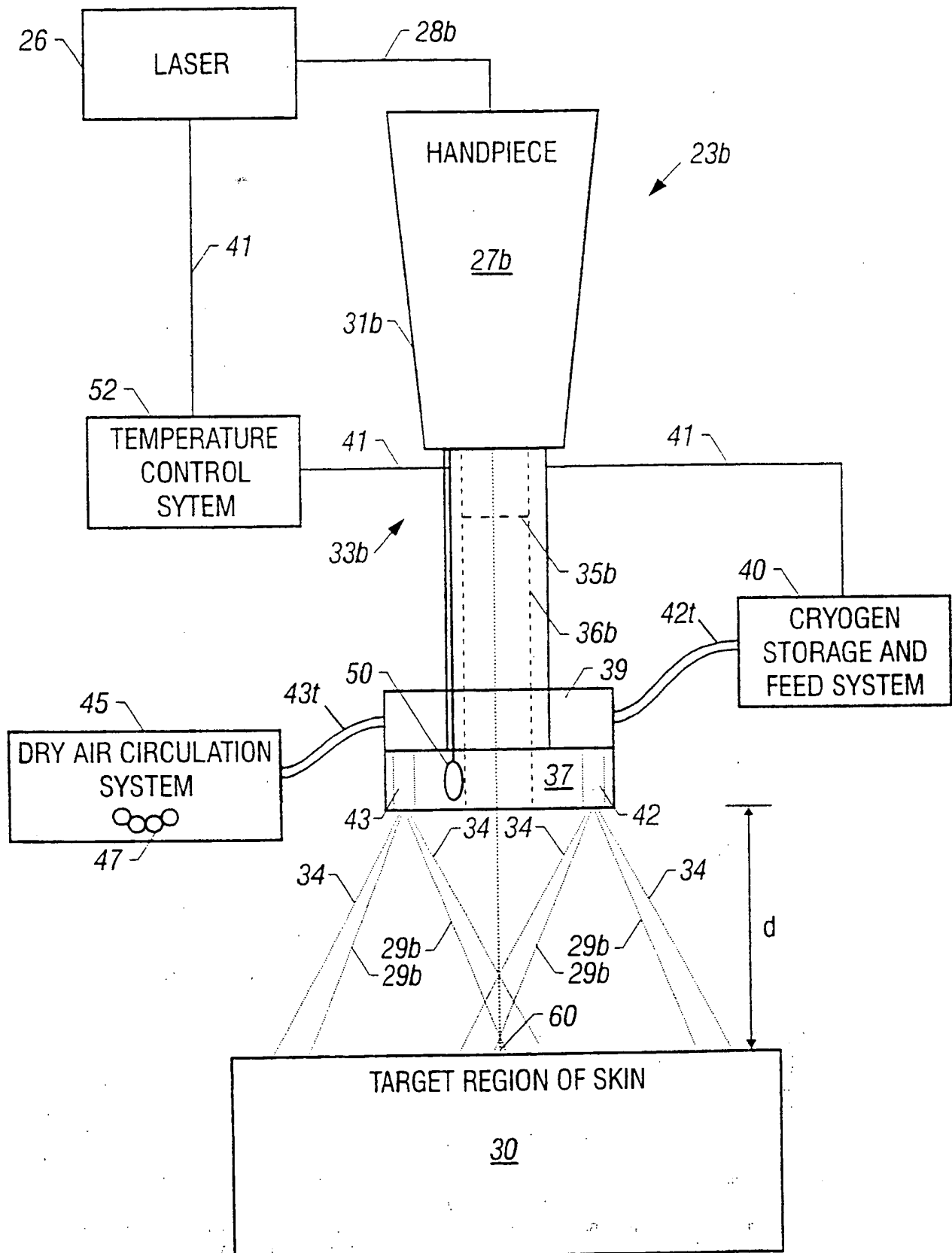
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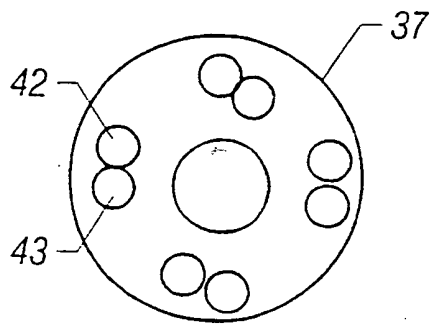
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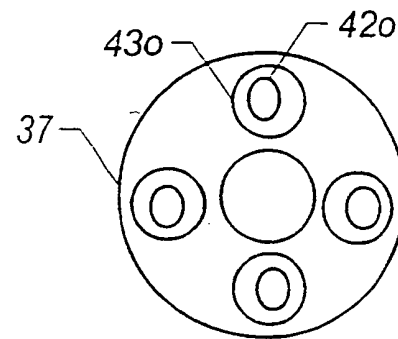
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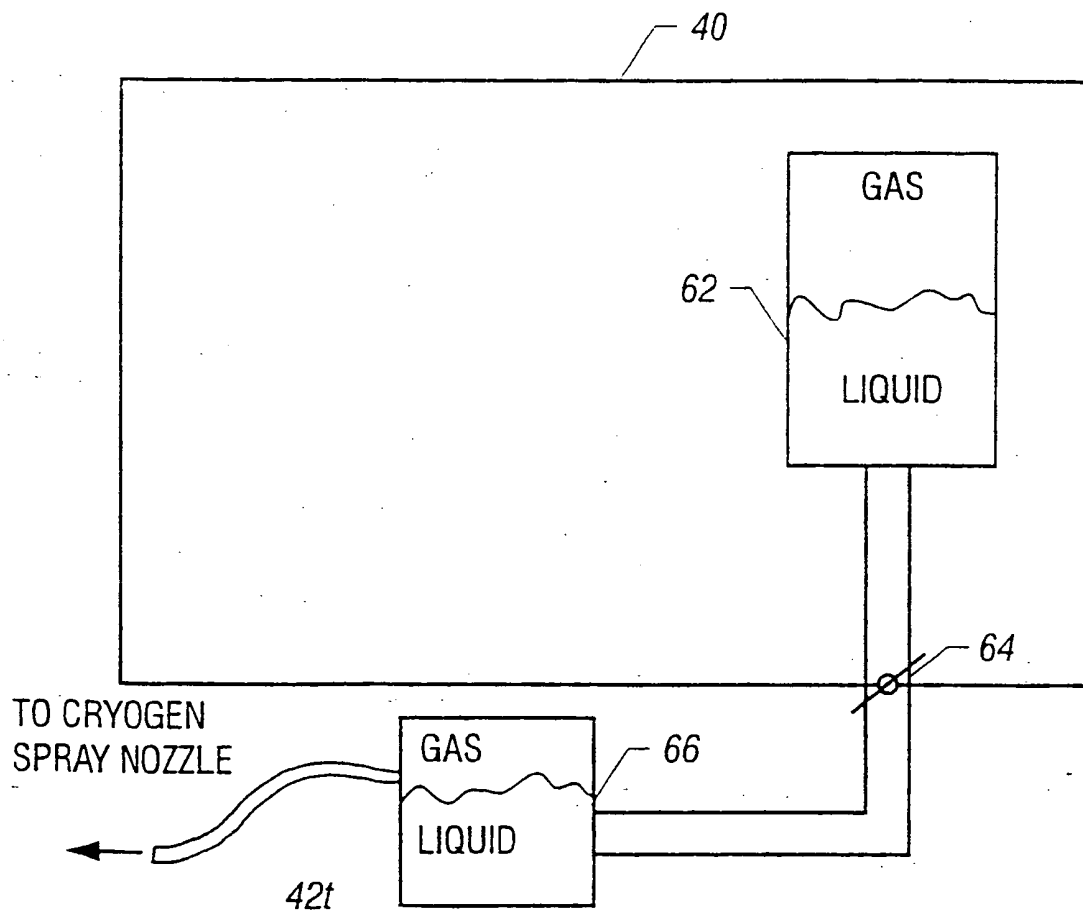
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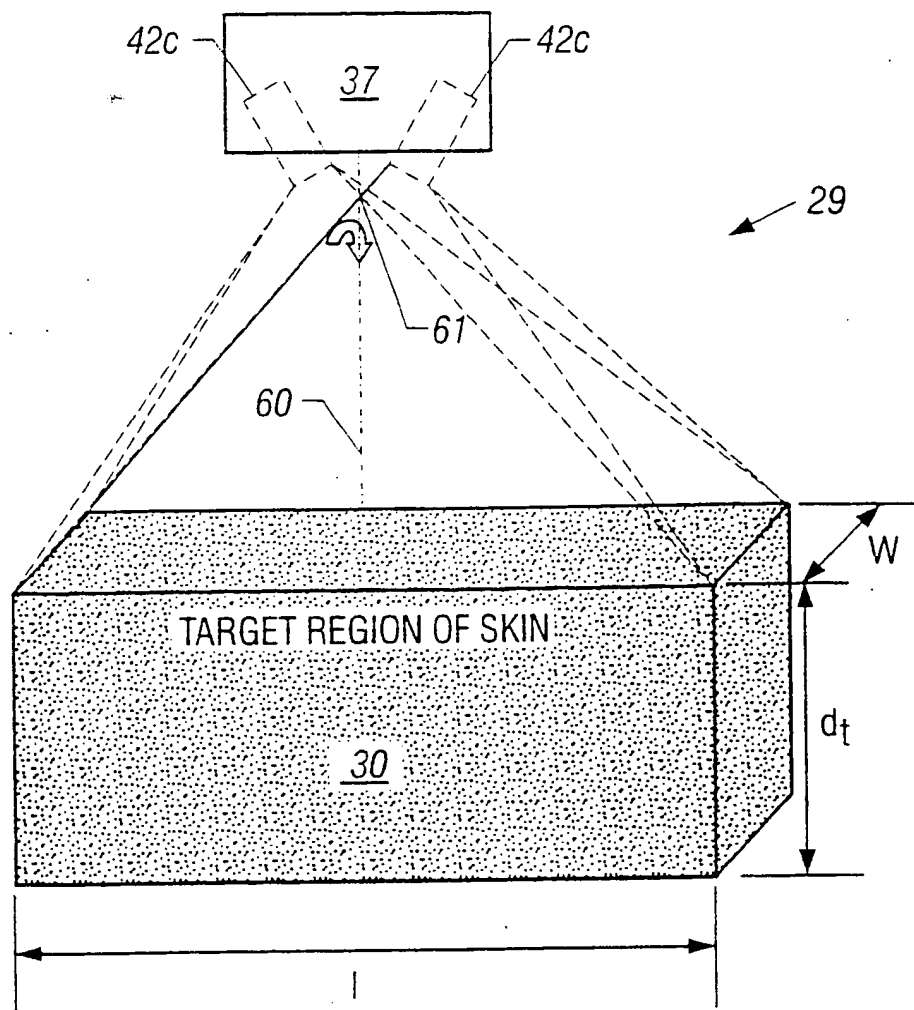
FIG. 14
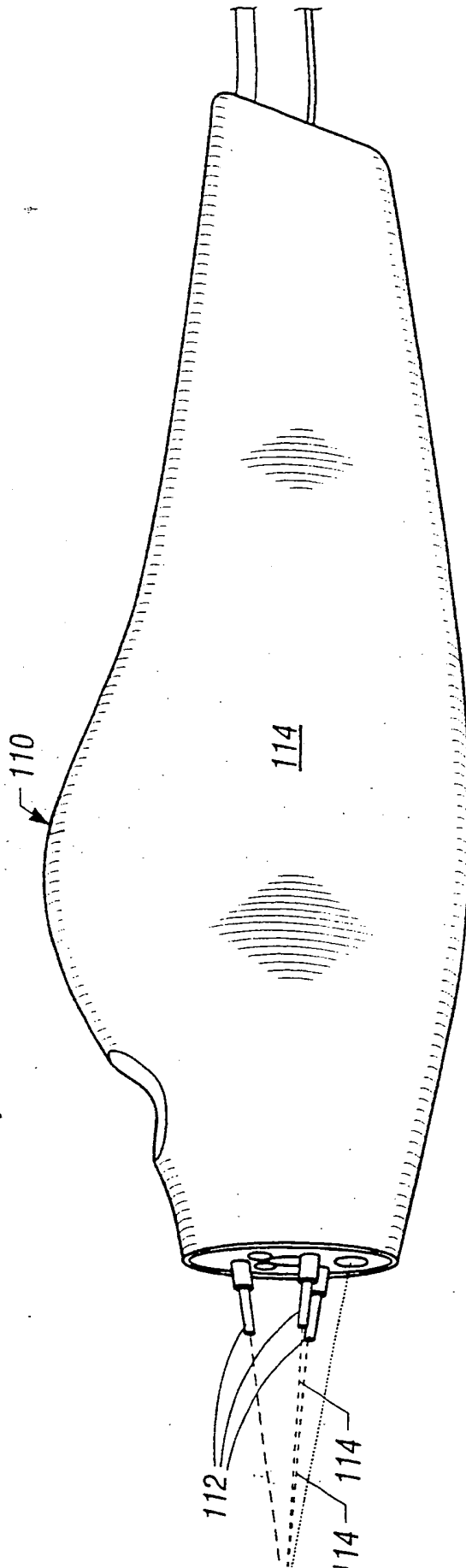
FIG. 15
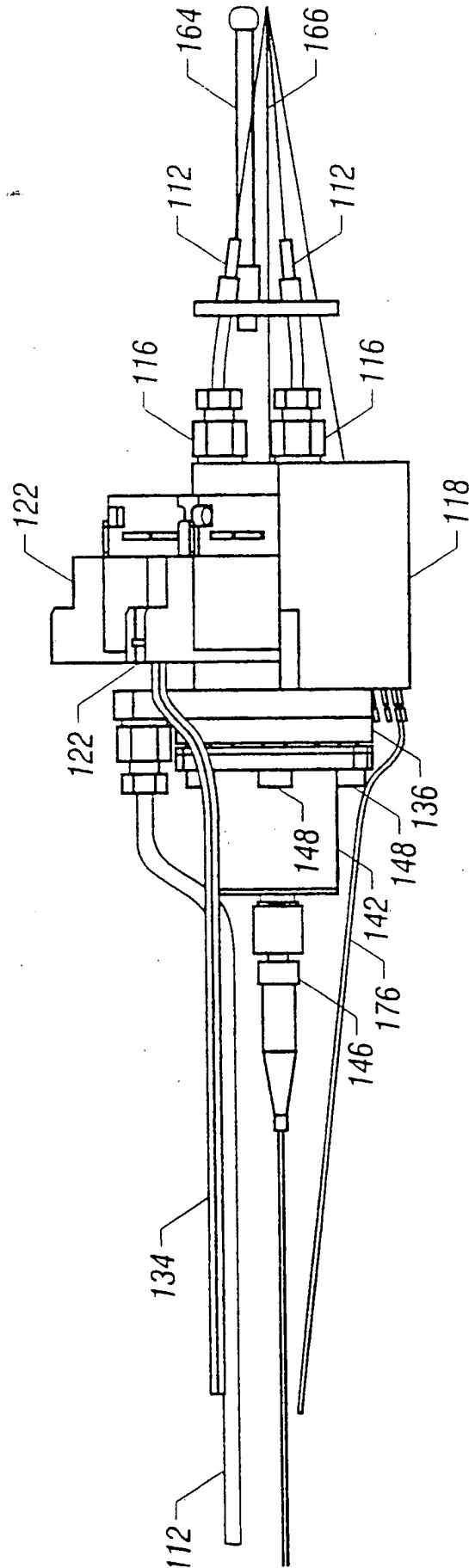
FIG. 16
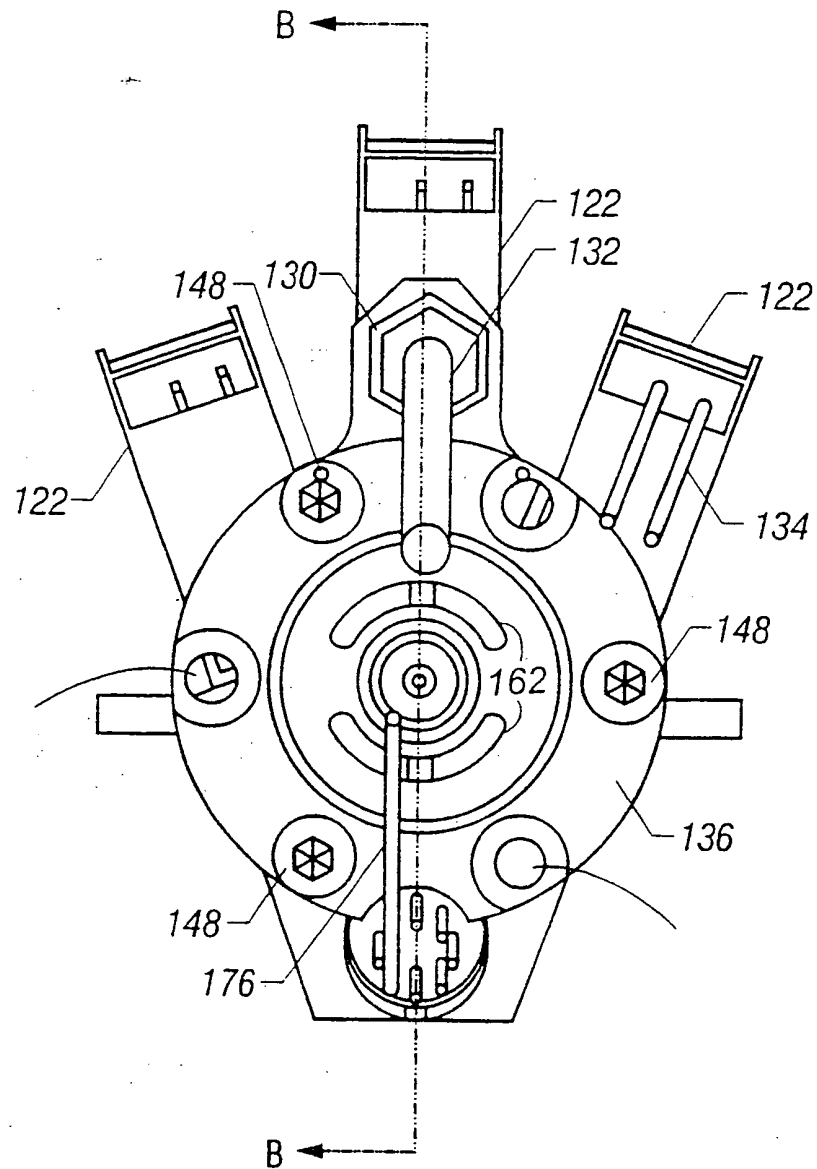
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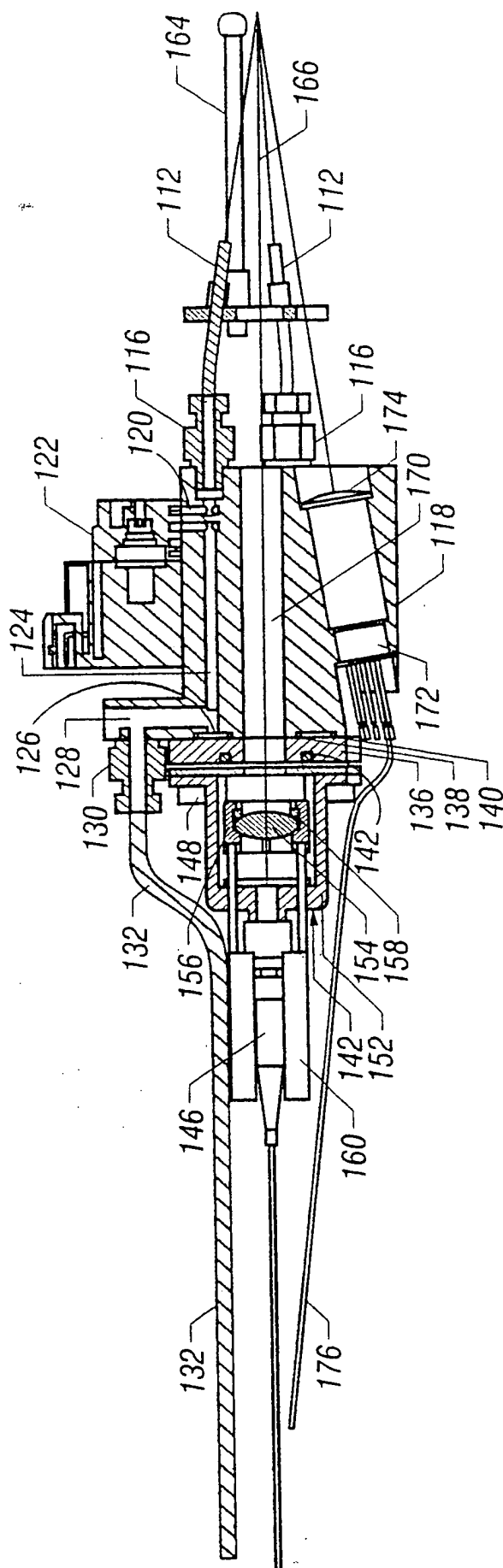
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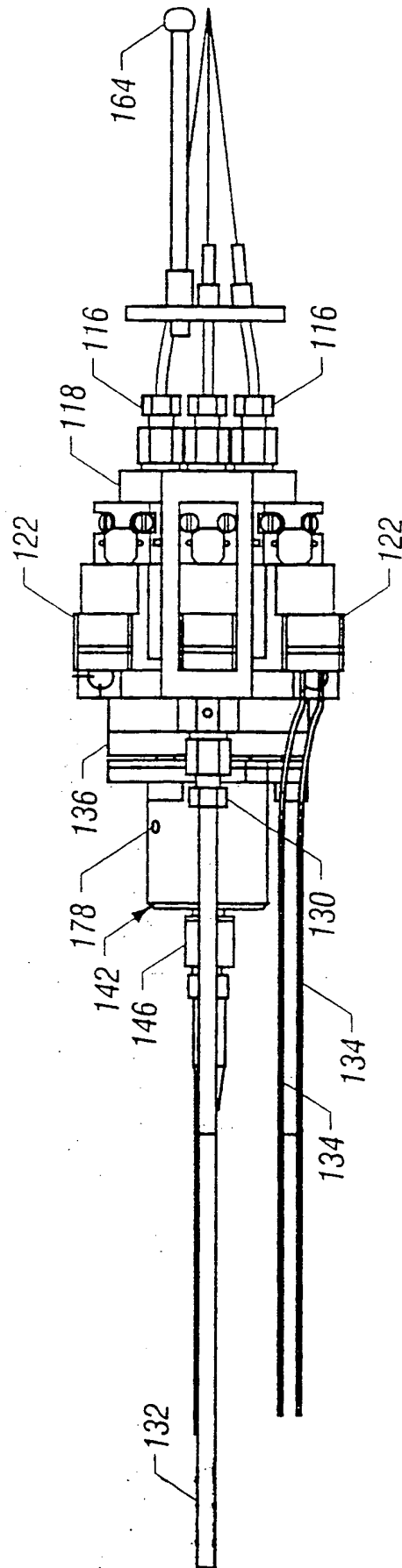
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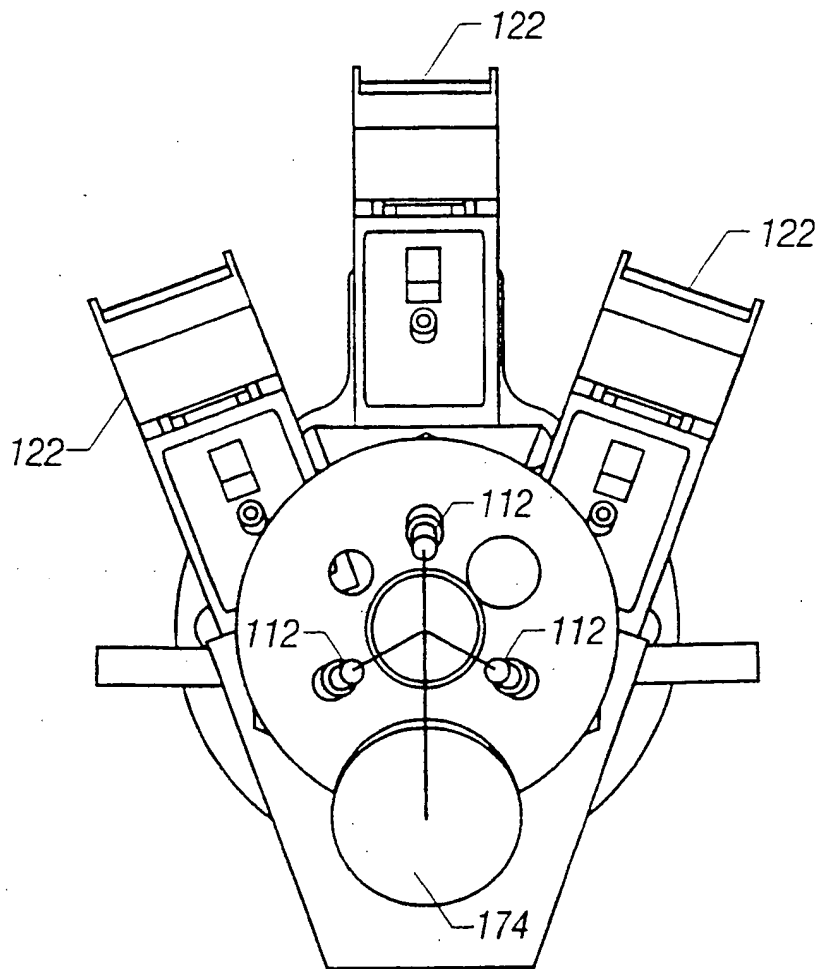
FIG. 20
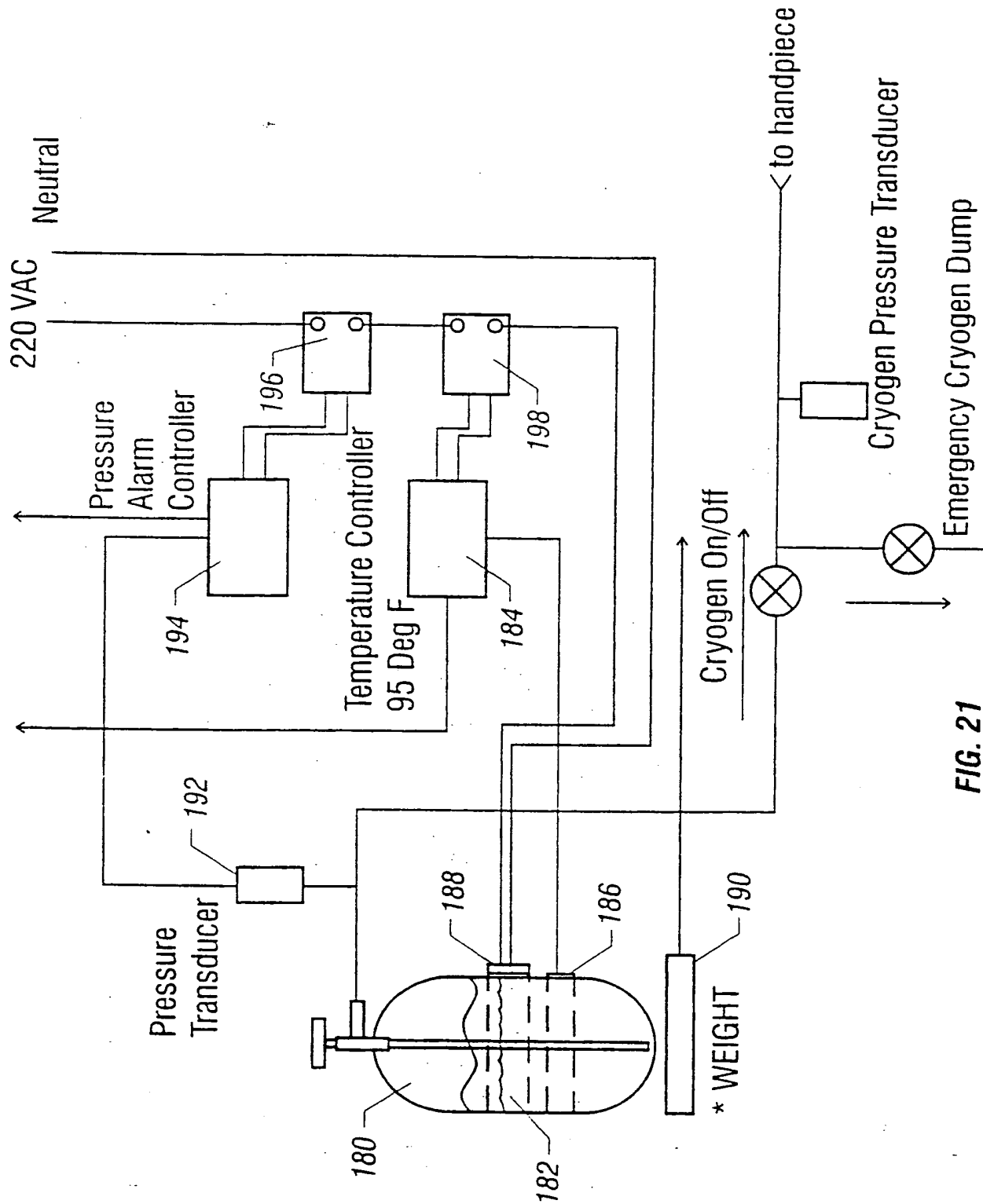
FIG. 21

20/20
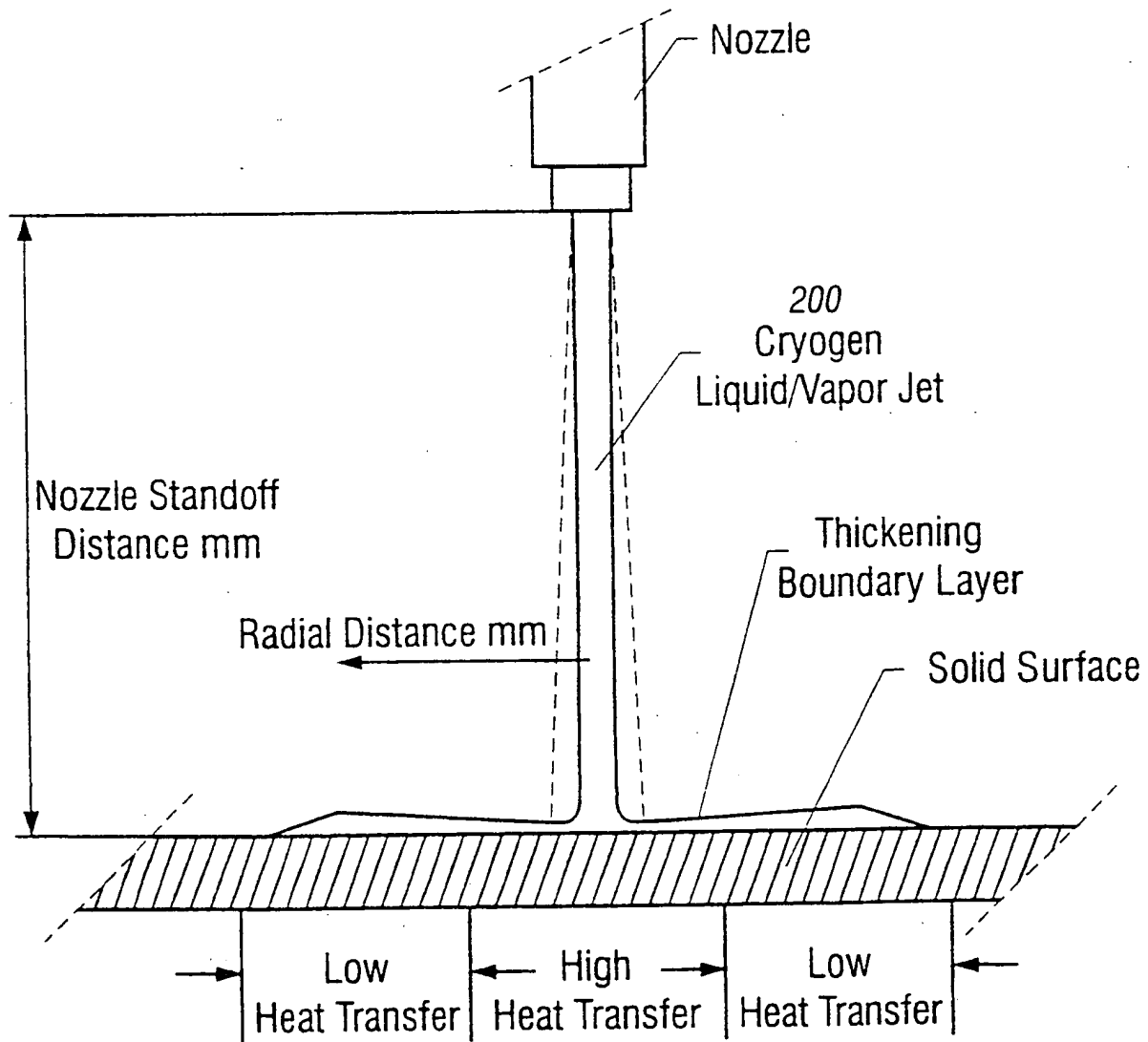
FIG. 22

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 6   A61B17/41

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6   A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 195 12 481 A (UNIV CALIFORNIA) 12 October 1995 see page 4, line 21 - page 5, line 33; figure 3	1,3,4
A	US 5 630 811 A (MILLER IAIN D) 20 May 1997 see column 10, line 33 - line 63; figure 6	1
A	US 5 057 104 A (CHESS CYRUS) 15 October 1991 see column 4, line 17 - line 44; figure 1	1
A	WO 97 00098 A (SVERDRUP LAWRENCE ;TANKOVICH NIKOLAI (US); THERMOLASE CORP (US); E) 3 January 1997 see abstract	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 March 1999	22/03/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl. Fax: (+31-70) 340-3016	Hansen, S

INTERNATIONAL SEARCH REPORT

Information on patent family members

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			WO	9742849 A	20-11-1997

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